COLADO J.B. HULEN GSA Spec. Paper 101 1966 (1968?)

and pebble conglomerate. In general, layering dips northeasterly from 25° to nearly vertical, 70°–80° NE being most common. Rotation of large blocks on high-angle faults locally has caused marked divergence from these trends and has offset or truncated northwesterly striking low-angle shear zones. Intensive shearing and formation of (recrystallized) pseudotachylyte is developed on two major high-angle fault sets (N. 25° W. and N. 40° E.).

Metamorphism in and near shear zones is characterized texturally by development of semischists plus phyllites, and mineralogically by crystallization of prehnite-pumpellyite facies assemblages. Metamorphic minerals, found both in sheared and weakly deformed rocks, include:

Quartz + albite + ripidolite + $2M_1$ mica (phengite) ± prehnite ± sphene ± calcite;
Pumpellyite or clinozoisite (rare).

Widespread quartz-rich veins contain prehnite + ripidolite ± calcite ± muscovite. Localized dynamothermal metamorphism superposed on regional burial metamorphism conditions (approximately 300° C., P^{tot} 3 kb, depth 10–12 km) is indicated by greater degree of development of metamorphic assemblages in sheared zones. Metamorphic reaction kinetics probably were controlled by energy change related to penetrative deformation. Time of metamorphism is speculative, but regional considerations suggest a pre-Upper Cretaceous age.

Detrital minerals and lithic clasts indicate a sediment source area comprising greenschist facies metamorphic rocks, granitic plutonic rocks, silicic-mafic volcanic rocks, and chert. Pre-Devonian to Permian rocks of these lithologies crop out 75 km north of Vancouver Island, B.C., and farther east in the San Juan Islands, Washington.

Late Quaternary Interaction of the Humboldt River and Lake Lahontan near Winnemucca, Nevada

HAWLEY, JOHN W., *Soil Conservation Service, Box 129, University Park, N. Mex. 88070*

Results of a study of late Quaternary valley fill near Winnemucca, Nevada, are utilized in a reconstruction of a shifting environmental sequence in an area where Lake Lahontan and Humboldt River deposits intertongue.

During the early part of the last major pluvial stage, Lake Lahontan expanded from a minimum (3800 feet) to a point (4200 feet) where initial flooding of the Winnemucca segment of the Humboldt Basin took place. Increased discharge of an ancestral Humboldt resulted initially in valley widening and entrenchment. As the lake base level rose to its 4360-foot maximum, a shift from valley-floor degradation to aggradation, as well as a transition from fluvial to lacustrine sedimentation, took place in progressively higher parts of the segment. Textural (CM) diagram plots based on mechanical analyses of samples from this sequence indicate a shift from tractive-current to quiet-water depositional environments.

Upon lake recession, cutting of the present river valley was initiated. Flood-plain surfaces preserved as terraces above the valley floor represent temporary halts in degradation and appear to be related to periods of increased river discharge associated with sub-4200-foot pluvial-lake maxima. The lithologic character and morphology of the terrace deposits indicate that pluvial river discharge was at least ten times greater than the bankfull discharge (1000 cfs) of the present meandering Humboldt channel. Maximum entrenchment of the valley is marked by a buried flood plain that is discontinuously covered by a volcanic ash bed tentatively correlated with the Mazama eruption.

Studies of Microearthquakes Associated with a Center of Seismicity in the Denver Area, Colorado

HEALY, JOHN H., and WAYNE H. JACKSON, *U. S. Geological Survey, Denver, Colo.*

A series of earthquakes ranging from negative magnitudes to magnitudes of four plus has occurred in a localized region northeast of Denver, Colorado, between 1962 and the present.

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BULLETIN 414

Covers Leach Humboldt Colado

NOTES ON SOME MINING DISTRICTS IN HUMBOLDT COUNTY, NEVADA

to index → this area is now mostly Pershing Co.

BY

FREDERICK LESLIE RANSOME

1909

WASHINGTON
GOVERNMENT PRINTING OFFICE

CONTENTS.

ILLUSTRATIONS.

NOTES ON SOME MINING DISTRICTS IN HUMBOLDT COUNTY, NEVADA.

By Frederick Leslie Ransome.

INTRODUCTION.

In the apportionment of my field season in 1908, a period of six weeks was allotted to a reconnaissance examination of that part of Humboldt County, Nev., lying between the fortieth and forty-first parallels and the one hundred and seventeenth and one hundred and nineteenth meridians. Within this area of about 7,000 square miles (see fig. 1) are the Seven Troughs, Rosebud, Star, Unionville (Buena Vista), Humboldt, Fitting, Chafey (Dun Glen, Sierra), Kennedy, and Adelaide (Gold Run) districts,[a] with many others of less note. North of the region particularly investigated is the Red Butte district and south of it is Coppereid (White Cloud district). Both of these were visited.

Some of the districts examined, such as Seven Troughs, Rosebud, and Red Butte, have been prospected only within the last two or three years; others, like Star City and Unionville, reached their acme of productiveness in the decade beginning with the year 1860 and have not yet participated in the recent general revival of mining activity in Nevada; one or two, like Chafey, have received new names and are being exploited in various ways that modern experience and ingenuity have devised for this purpose; still others, like Adelaide, have been intermittently active for over thirty years, oscillating between prosperity and decay.

All of the country traversed, with the exception of that adjacent to Red Butte, was mapped geologically by the Fortieth Parallel Survey, and that map,[b] on a scale of 4 miles to the inch, with a contour interval of 300 feet, is still the best one, although there have been many

[a] In general the names of districts as here used are those of the principal settlements. Some of the mining districts, as originally organized for purposes of record and regulation, embrace large tracts of which the names and boundaries have little significance except to local surveyors and official recorders.

[b] U. S. Geol. Expl. 40th Par., atlas, Map V, 1876. (The topographic sheets are not contoured, but show the relief by shading.)

changes in place names in the thirty-three years that have elapsed since its publication. In general, the "granites" of this region, described as Archean in the Fortieth Parallel Survey reports, are intrusive in

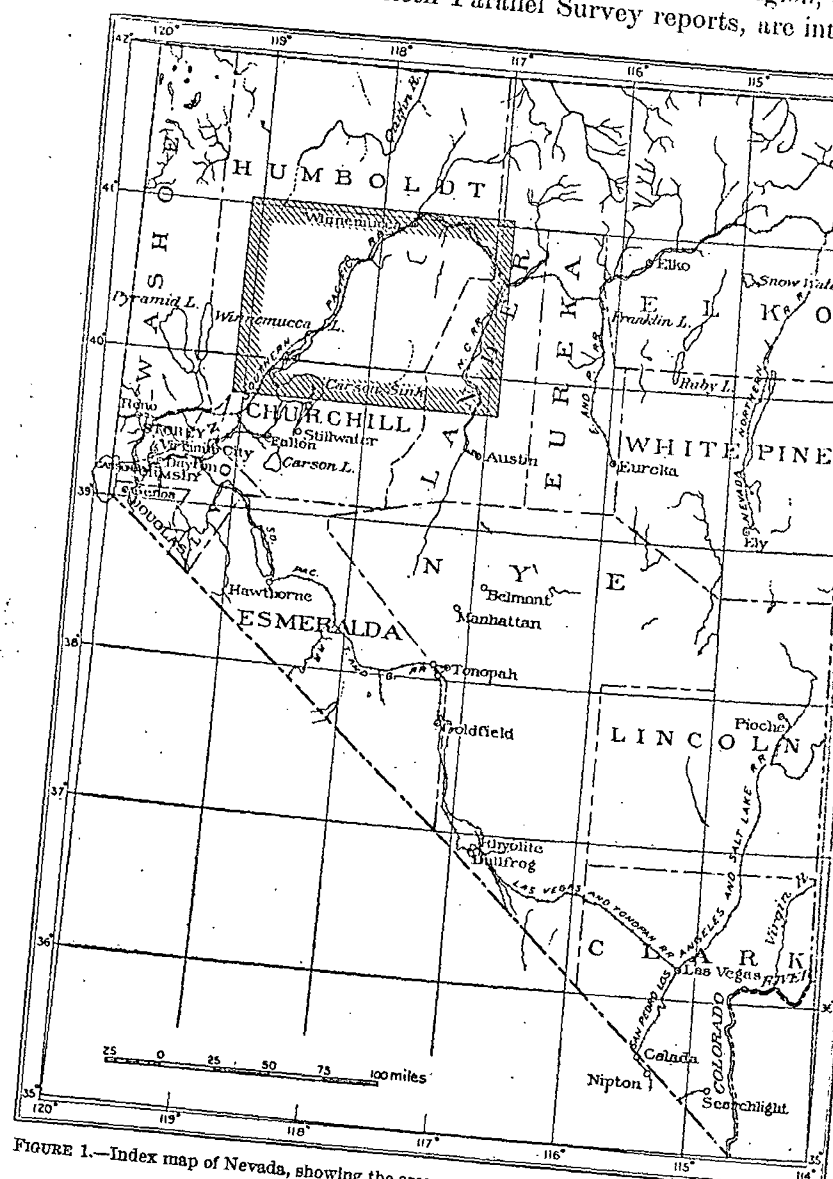

FIGURE 1.—Index map of Nevada, showing the area covered in part by the reconnaissance of 1908.

Mesozoic rocks; much of the material described as quartzite in the Triassic is rhyolite, and thorough study would change many of the names applied to the igneous rocks. During the last thirty years the mining districts of Humboldt County have received little attention

from geologists, and the present reconnaissance was undertaken in the belief that even a hasty review of the region, while not likely to yield results of much scientific importance, might serve as the basis for a preliminary report that should be of some value to those interested in the mining development of north-central Nevada.

It is a pleasure to acknowledge my indebtedness to the mining men of the region for courtesies too numerous to mention, and especially to Mr. John T. Reid, of Lovelock, and Mr. W. D. Adamson, of Winnemucca, who gave generously of their time and information.

ITINERARY.

From Lovelock, on the Southern Pacific Railroad (see Pl. I), a trip of five days' duration was made to the Seven Troughs district, 30 miles northwest of that town, and return. Two days were next spent in visiting Coppereid, in the White Cloud district, Churchill County, about 25 miles southeast of Lovelock. A wagon and team were then hired at Lovelock, and the Humboldt Range was crossed by way of the Humboldt Queen mine and Limerick and American canyons to Fitting, or Spring Valley, as it is sometimes called. Thence I drove north to Unionville, and from that place turned southeast across the East Range to Kennedy, on the west side of Pleasant Valley. From Kennedy the route was south, past Sou Springs to Boyer's ranch, on the northwest side of Dixie Valley, which was a convenient place from which to examine the nickel and cobalt mines of Cottonwood Canyon, in the Stillwater Range. From Boyer's ranch the return to Lovelock was made over the Stillwater Range by way of Kitten Spring, across the valley of Carson Sink, and through Cole Canyon, east of Oreana, which separates the Humboldt Range into two distinct divisions, the northern one being sometimes referred to as the Star Peak Range and the southern one as the Humboldt Lake Range.[a] This trip occupied six days.

From Ryepatch, on the Southern Pacific Railroad, a visit was paid to the Ryepatch mine and from Humboldt House to a cinnabar prospect in Eldorado Canyon, on the west side of Star Peak. Humboldt House also was the starting point for a trip lasting three days to the Red Butte and Rosebud districts. The Chafey district and the Sheba mine in Star Canyon were reached from Mill City, and a short excursion was made from Golconda, 12 miles east of Winnemucca, to the Adelaide mine. The Galena and other districts accessible from Battle Mountain were not visited, the reconnaissance having already taken more time than could well be spared from other duties.

[a] Louderback, G. D., Basin range structure of the Humboldt region: Bull. Geol. Soc. America, vol. 15, 1904, p. 294.

GENERAL HISTORY OF MINING DEVELOPMENT.

Mining activity began in this part of Nevada about the year 1860 with the organization of the Humboldt district, on the northwest slope of Star Peak. At that time the Central Pacific Railroad Company was not yet incorporated, supplies and machinery were hauled tediously in wagons from Marysville or Sacramento, and the project of a transcontinental railway was little more than a dream. The Star and Buena Vista districts were organized in 1861, and during the civil war and the recovery from that conflict these isolated desert communities attained their greatest prosperity. Mines were opened along both flanks of the Humboldt Range, and the settlements of Star City and Unionville soon grew to importance. At Oreana, on the banks of Humboldt River, smelting works were built to treat ore from the Montezuma mine, in the Trinity district, organized in 1863. Special interest attaches to this smelter, as it was the first in Nevada from which lead was shipped in commercial quantities, and it contests with Argenta, Mont., the honor of being the birthplace of the present gigantic silver-lead smelting industry of the United States. Its history, however, was brief; after various failures the furnaces were at length operated successfully in 1865, but were practically abandoned about 1870. The metallurgical processes employed have been described by R. W. Raymond [a] and James D. Hague.[b] The fuel was charcoal and the products of the furnace, silver bullion and an alloy of lead and antimony, were shipped to San Francisco.

On the east side of the Humboldt Range the discovery of a rich body of silver ore in the Sheba mine close to the surface led to the rapid growth of Star City from 1861 to 1865. The town had two hotels, express and telegraph offices, daily mails, and a population estimated at about 1,000. In 1871 Raymond [c] reported the town as nearly abandoned, although at that time additional ore had been found below the levels from which the original bonanza had been stoped. At present only two men are living in the canyon, the mines are idle, two or three ruined stone cabins are all that remain of the town, and the little brook, once foul with tailings and town refuse, is now the home of trout and sparkles through diminutive hay meadows.

At Unionville the principal mine was the Arizona, owned and operated by Fall & Temple. Other important workings were those of the Silver, Pioneer, and Manitowoc mines. The Arizona mine is said to have been bought by John C. Fall in 1862 for $5,000. Soon

[a] Mineral resources of the States and Territories west of the Rocky Mountains, Washington, 1869, pp. 130–132.

[b] Mining industry, U. S. Geol. Expl. 40th Par., 1870, pp. 300–308.

[c] Statistics of mines and mining, etc., Washington, 1872, p. 208.

fterward he built the 5-stamp Pioneer mill, the machinery and aterials for which were hauled by ox teams from Marysville, Cal. n aerial tramway was later constructed from the north workings of e Arizona mine to the mill in the canyon, several hundred feet elow. Other mills were subsequently built farther down the canyon, nd in 1870 there were three mills of 10 stamps each in operation. Vater power was used in the first mill, but it soon became necessary to upplement this with steam. Since the principal mines were opened n different parts of a nearly horizontal vein that outcropped in an lliptical curve about a hill, litigation was inevitable, and after some ontroversy the Arizona and Silver companies consolidated in 1870 s the Arizona Association. The average cost of mining and milling at that time was about $24 a ton, having not long before been lowered by the introduction of Chinese labor in the mills. Skilled miners were paid $4 a day or $3 a day with board. There was almost no gold in the ores, which were treated by pan amalgamation, the tailings, after standing for a time, being re-treated by the same process. The milling ore averaged about $60 a ton, and some ore, shipped crude to San Francisco, ranged from $500 a ton upward. One lot of 170 tons shipped in 1871 is reported by Raymond [a] to have netted $78,000, and the total ore mined in that year by the Arizona Association is given as 7,000 tons. In 1873 the output had declined to 3,915 tons, of which 81 tons of about $330 grade was shipped to San Francisco. The mine continued to be worked until 1880, since when little has been done with it. It produced in all (including the output of the Henning or Wheeler mine, which yielded less than 5 per cent of the whole) about $3,000,000 from approximately 80,000 tons of ore. In 1899 the property was brought by John Ross and Neal Carmichael, the present owners, who have not, however, resumed work on a commercial scale.

From 1860 nearly to 1880 Unionville, although perhaps rivaled or surpassed for a short time by Star City, was on the whole the most important town in the Humboldt region, and was the local supply point for many smaller communities in neighboring mining districts.

There was considerable activity during this period near Dun Glen (now known as Chafey), in the Sierra district. The most productive mine in the seventies appears to have been the Tallulah, 2 miles northwest of Dun Glen. Afterward the Auld Lang Syne mine became the leading one of the district. The Monroe and Auburn mines also were active.

On the west side of the Humboldt Range mining was in progress at many places during the period when Unionville flourished. Among

[a] Statistics of mines and mining, etc., Washington, 1873, p. 208.

the noted silver mines on that side of the range are the Humboldt Queen and the Ryepatch. The latter, which is reported to have produced over $1,000,000, was known before 1872 as the Butte mine. It has been idle for over twenty years.

It is to be noted that most of the mines in the Humboldt Range were opened and were worked most extensively before the completion of the Central Pacific Railroad. The great improvement in mining facilities brought about by railway communication was not sufficient to offset the diminution in tenor of the ore bodies, as they were followed below their enriched portions, and the decline in the price of silver consequent upon the demonetization of that metal.

Although the mines of the Humboldt Range have yielded far more silver than gold, placer mining was at one time an important industry, especially in American Canyon, 12 miles south of Unionville. Operations began there about 1881 and were prosecuted actively until about 1895. The placers were first worked by Americans, who are reported to have taken out gold to the value of about $1,000,000. The ground, however, soon passed into the possession of Chinese, who formed a considerable settlement in American Canyon and mined the gravels with skill and assiduity by drifting from countless narrow shafts ranging from 40 to 85 feet deep. How much gold they obtained is unknown, but some estimates, doubtless much exaggerated, place the total at about $10,000,000.

In Cottonwood Canyon, on the east slope of the Stillwater Range, near latitude 40°, are nickel and cobalt mines, which were opened about 1882, a car of nickel ore being shipped in that year to Camden, N. J. The Nickel mine, owned by the American Nickel Company, was worked until about 1890. It was again opened in 1904, but has been idle since 1907. A small smelter was built and a little matte, probably not over 50 tons, was produced. Attempts were made also to extract nickel salts with sulphuric acid, with what success is not known.

The Lovelock mine, a little farther up the canyon, has probably shipped about 500 tons of nickel-cobalt ore, which was hauled to Lovelock by teams returning from the Bernice silver and antimony district in the Augusta Mountains. A diminutive furnace was erected but was not successful.

The Kennedy district, also on the east side of the Stillwater Range and about 25 miles southeast of Unionville, first attracted attention in 1890. Kennedy soon became a flourishing town; mills were built and considerable work was done in the Gold Note, Imperial, and other mines. After the exhaustion of the oxidized pay shoots the amalgamating mills proved unfit for coping with the complex gold-silver-lead ores, and since 1904 the district has sunk into decay. No mining

as in progress in 1908. The total output of the district probably es not exceed $120,000, mostly from ore of shipping grade.

The principal events of the past few years in the Humboldt region ave been the opening of the Seven Troughs district in 1907 and the evival of mining in the vicinity of Dun Glen or Chafey in 1908. The Rosebud bubble, which collapsed in 1907, has merely added one more o a long list of such failures in Nevada. The various good and evil ttributes on which mining "booms" depend are as a rule curiously blended or contrasted. Energy, hope, cupidity, credulity, and many other qualities all contribute to the local sentiment that applauds the "booster," no matter how extravagant his claims, and that defers the recognition of truth until the moment of disaster. The fact that a mining district is injured, not helped, by misrepresentation is forgotten by those who buy and stay, ignored by those who sell and go.

LITERATURE.

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GABB, W. M. Paleontology, vol. 1, Geol. Survey of California, 1864, pp. 19–35. (Describes Triassic fossils from the Humboldt Range and from near Dun Glen.)

HAGUE, ARNOLD. Fish Creek and Battle Mountains (pp. 660–672); Havillah and Pah-Ute ranges (pp. 673–712); West Humboldt region (pp. 713–750); Montezuma Range and Kawsoh Mountains (pp. 751–774). U. S. Geol. Expl. 40th Par., vol. 2, 1877. (Describes the general geology.)

HAGUE, ARNOLD, and EMMONS, S. F. Region of the mud lakes. U. S. Geol. Expl. 40th Par., vol. 2, 1877, pp. 775–800. (Describes geology.)

HAGUE, JAMES D. Mining and milling in western Nevada. U. S. Geol. Expl. 40th Par., vol. 3, Mining industry, 1870, pp. 296–319. (Describes the Montezuma mine in the Trinity district, the smelting works at Oreana, and the mines of the Buena Vista, Star, Sierra, Gold Run, and Battle Mountain districts.)

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Raymond, Rossiter W. Mineral resources of the States and Territories west of the Rocky Mountains. Washington, 1869, pp. 117–133. (Notes on the history and development of the Battle Mountain, Black Rock, Buena Vista, Central, Eldorado, Gold Run, Humboldt, Orofino, Sacramento, Sierra, Star, Trinity, and Winnemucca districts.)

——— Statistics of mines and mining in the States and Territories west of the Rocky Mountains. Washington, 1870–1874. (Contains much information concerning the development and working of the mines during the period covered.)

Russell, Israel C. Geological history of Lake Lahontan. Mon. U. S. Geol. Survey, vol. 11, 1885. (Describes the great Quaternary lake that occupied the valleys of the Humboldt region.)

Spurr, J. E. Origin and structure of the basin ranges. Bull. Geol. Soc. America, vol. 12, 1901, pp. 217–270. (Discusses incidentally the structure of some of the ranges visited in the course of the present reconnaissance. Mr. Spurr's own field work, however, was south of the fortieth parallel.)

[Wisker, A. L.] Chafey, Nev. Min. and Sci. Press, Nov. 7, 1908, pp. 625–626. (A good brief sketch of the history of the district and of mining conditions therein during the summer of 1908.)

SEVEN TROUGHS DISTRICT.

INTRODUCTION.

The Seven Troughs district, which is about 30 miles northwest of Lovelock, a flourishing town on the main line of the Southern Pacific Railroad, lies on the east slope of a minor range designated on the Fortieth Parallel Survey map[a] as the Pah-tson Mountains, but now popularly known as the Seven Troughs Mountains.[b] The higher parts of the mountains are dotted with junipers and the larger ravines contain small perennial streams. Grass flourishes on some slopes and for over thirty years the region has been used as a range for sheep and cattle. The watering places maintained in connection with this pastoral occupancy have given to the new mining district its name.

The road from Lovelock runs for a few miles through the irrigated farming land of Humboldt Valley and then crosses obliquely in a northerly direction a broad and relatively low part of the Trinity Range consisting of granitic and slaty rocks partly buried under rhyolitic and basaltic flows. From the northwest base of this range the road stretches straight across the bare and nearly level expanse of the northeast arm of Sage Valley for 9 or 10 miles, to the foot of the Seven Troughs Mountains. A more unsatisfactory road material than the mixture of stones and ashy soil that floors this arid basin can hardly be imagined, and the many abandoned deep-rutted tracks show that at times no road at all is preferable to one in which the depth of the dust-filled chuck holes is a subject for anxious speculation.

[a] U. S. Geol. Expl. 40th Par., atlas, Map V, west half.
[b] Occasionally referred to also as the Stonehouse Range.

Supplies are hauled by teams from Lovelock. Passengers may ach the district most conveniently from the same point by the dinary stage line or by automobiles, which meet the transcontinental ains and ply over a little better road than is used by horse-drawn hicles.

There are four little towns in the district, three of which, Vernon, azuma, and Farrell, are situated at the east base of the range. ernon, the southernmost of the three, was the chief settlement in e district early in 1908, but had lost its preeminence by August f that year, most of the activity then centering about Mazuma, 2½ iles north-northeast of Vernon, and about Seven Troughs, which 1¼ miles west-northwest of Mazuma, higher up the same canyon. arrell, 3 or 4 miles north of Mazuma, has at no time been as important s the other settlements.

The ravine in which are the towns of Mazuma and Seven Troughs s known as Seven Troughs Canyon. North of it in order are Wildhorse, Burnt, and Stonehouse canyons, the latter embouching at Farrell. Victor Canyon is a short minor ravine between Burnt and Stonehouse canyons. All three of the main ravines contain water the year round, part of that from Burnt Canyon being piped to Mazuma.

It is difficult to determine when prospecting began in this district, but there is little record of any work prior to 1905, and it was not until early in 1907 that the veins began to attract other than local attention. The Mazuma Hills mine was opened in that year, and its success, with the subsequent discoveries in the Fairview and Kindergarten mines and in various leases, soon made Seven Troughs a familiar name in the mining press.

GENERAL GEOLOGY.

TOPOGRAPHY.

The Seven Troughs Mountains have a length of 24 miles and trend 20° east of north. The greatest width of the range is 8 miles. Its crest culminates in a group of three summits, which attain altitudes of about 3,000 feet above the desert plains that surround the range on all sides but the north. The highest and middle summit is Granite Peak. The one southwest of it, of schist, is designated Pahkeah Peak on the Fortieth Parallel Survey map. A low, broad pass, occupied according to this map by Miocene lake beds belonging to the Truckee formation, separates the north end of the Seven Troughs Range from the longer Trinity Range and from the Kamma Mountains, a small group within which is the Rosebud mining district and the Rabbit Hole sulphur mine.

EARLY EXPLORATION.

The Fortieth Parallel Survey map represents the Seven Troughs Mountains as consisting of a mass of Archean rocks and granite, exposed on the higher summits and over much of the west slope, but covered in the southern and eastern parts of the range by Tertiary rhyolite and subordinate overlying flows of basalt. An area of Jurassic rocks, about 5 miles long and 1 mile wide, is also shown on the east slope, just north of what is now the central part of the Seven Troughs mining district. Hague and Emmons [a] state that these rocks comprise "blue limestone and shales, which, on grounds of general probability, but without paleontological or distinct stratigraphical evidence, have been referred to the Jurassic formation."

The Archean rocks are described by the same writers [b] as very fine grained micaceous schists, distinctly bedded and standing at high angles. These are said to be cut by the granite, which, as Hague and Emmons point out, is of basic character, very different from the known Archean granites of the region, but closely resembling the rocks of the great intrusive masses, supposedly of post-Jurassic age, of the Sierra Nevada and of some of the prominent ranges of the western part of the Great Basin. They note also some small exposures of an older granite, probably Archean, on the west slope of the range.

The volcanic rocks are briefly described by the same explorers,[c] and some of the perlitic varieties were studied and figured by Zirkel.[d] Little information is given concerning the succession and structure of the lavas, and the localities particularly described are all outside of the district now being prospected.

Apparently no mining whatever was in progress in these mountains when Hague and Emmons visited them.

PRE-TERTIARY ROCKS.

The known ore deposits of the Seven Troughs Range are all in the Tertiary volcanic rocks, and consequently a small part only of the four days spent in the district could be devoted to the older formations. North of Mazuma the so-called Jurassic rocks appear first in Burnt Canyon as a northeast-southwest belt of indurated clay slate about half a mile wide. This belt appears to correspond at this place to a low ridge, which, after having been completely buried under lava flows, has been uncovered again by erosion. The slate extends northeast and forms the rounded foothills just west of Farrell. It was found to be exposed westward along Stonehouse Canyon nearly to its head, and the belt is thus two or three times as wide as is shown by

[a] U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 782.
[b] Op. cit., p. 776.
[c] Op. cit., pp. 779-780.
[d] U. S. Geol. Expl. 40th Par., vol. 6, 1876, pp. 208-209, Pls. VII, 2; IX, 2 and 3; and XII, 2.

Hague and Emmons, who evidently did not traverse this ravine and, naturally enough, mapped only the rhyolitic rocks visible on the ridges. At the old stone cabin from which the canyon gets its name, a mile or two west of Farrell, the slate is well exposed and dips about 20° E., bedding and cleavage being parallel. Farther up the canyon the dip varies and the slate is cut by dikes of a light-colored rock, presumably rhyolite. Near the head of the ravine the slate is intruded and metamorphosed by the "younger granite," described by Hague and Emmons. This metamorphosed material was mapped as Archean by these observers, and since the main mass of supposed Archean west of Pahkeah Peak consists, according to their description, of bedded slaty schists, there is a suggestion that these also may be metamorphosed post-Archean sediments. There was no opportunity in 1908 to investigate this problem; in fact, not having the Fortieth Parallel Survey map at hand, I was unaware, while in the field, that it had arisen.

The intrusive granitic rock at the head of Stonehouse Canyon is a fresh, medium-granular, rather dark gray rock, which evidently is not very quartzose and contains a large proportion of plagioclase. Only one specimen was collected and the mass undoubtedly contains other varieties than the one here described. The microscope shows the rock to be a granodiorite, of which the constituents are a plagioclase near andesine, orthoclase, microcline, quartz, hornblende, biotite, apatite, and magnetite. The plagioclase is a little more abundant than the alkalic fedspars.

The rock from the summit of Granite Peak was analyzed by Prof. Thomas M. Drown as follows:

Chemical analysis of granodiorite from Granite Peak.[a]

SiO_2	64.02
Al_2O_3	17.60
FeO	4.03
MgO	1.27
CaO	4.38
Na_2O	4.79
K_2O	2.62
Loss on ignition	.80
MnO	.16
	99.67

This specimen is said by Hague and Emmons to be typical of the mass, and their suggestion of its similarity to the granodiorite of the Sierra Nevada has been fully borne out by later work in that range.

[a] U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 779.

TERTIARY VOLCANIC ROCKS.

The prevailing rock of the low, rounded hills on the edge of the [illegible] Valley at Mazuma and for a mile or more up Seven Troughs Canyon is a pale reddish-brown lava, much of which shows conspicuous [illegible] lamination and a platy fracture. Some varieties are light [illegible] compact lithoidal texture, and contain minute phenocrysts of [illegible] and biotite; other kinds are brittle perlitic glasses. Although [illegible] rock is not visibly quartzose, its general appearance is so rhyolitic [illegible] little doubt of its siliceous character arose in the field, especially [illegible] it was mapped as rhyolite by the geologists of the Fortieth Parallel Survey. The microscope shows, however, that neither quartz nor [illegible] orthoclase is present in identifiable crystals, but that phenocrysts [illegible] labradorite and biotite lie in a very glassy groundmass containing [illegible] plagioclase microlites. Some ill-defined aggregates of magnetite [illegible] gest the former presence of small phenocrysts of hornblende that [illegible] undergone magmatic resorption. The rock accordingly is not a [illegible] lite but, pending chemical analysis, must provisionally be classed [illegible] mica andesite, unusually poor in femic constituents. Much of it [illegible] mica andesite vitrophyre.

Associated with the mica andesite, which appears to occur in [illegible] eral thin flows, is at least one flow of vesicular basalt, some of which [illegible] exposed on the slope just north of the west end of Mazuma.

The mica andesite, with a general dip to the east, is the principal [illegible] rock of the ridges on both sides of the road from Mazuma westward [illegible] Seven Troughs. Here the canyon expands into a little amphitheater [illegible] formed by two short lateral ravines that open north and south on the [illegible] main east-west gorge. The northern and longer ravine heads in a [illegible] saddle, through which passes the trail from Seven Troughs to Wild[illegible] horse Canyon. The southern ravine, which is much shorter and [illegible] steeper, rises to a higher saddle, through which goes the trail to the [illegible] Fairview mine and to Vernon. The length of the amphitheater [illegible] about a mile and its width about one-fourth mile. Structurally it [illegible] appears to correspond to a sharp north-south anticline, along which [illegible] the mica andesite has been eroded, exposing older and [illegible] softer rocks beneath it. Consequently the andesite in general [illegible] the basin and the other rocks occupy its lower part.

Directly under the vitrophyric andesite there is, as a rule, a flow of [illegible] basalt. The thickness of this is not known but appears to vary [illegible] greatly. Much of it is vesicular, and transitions from compact to [illegible] vesicular varieties are in some places abrupt. Some parts of the flow [illegible] are a brittle glass and must have been very quickly cooled. Under [illegible] this basalt and occupying the bottom of the Seven Troughs amphi[illegible] theater is a volcanic complex of rhyolite, basalt, mica andesite, tuffs, [illegible] arkosic sandstones, and possibly other rocks of which the structural [illegible]

[illegible]ions are as yet very imperfectly known and probably can be as[illegible]ained only by careful mapping and detailed microscopic work. [illegible] oldest rocks appear to be glassy tuffs, in part rhyolitic and in [illegible] basaltic, and arkosic grits. Interbedded with these is at least [illegible] flow of glassy amygdaloidal basalt. These are cut by dikes of [illegible]pact basalt and of a light-colored rock which is apparently the [illegible]valent of the mica andesite flows already described. One dike of [illegible] rock extends from Seven Troughs northward nearly to the saddle [illegible]ing into Wildhorse Canyon and forms a little ridge east of the [illegible]cipal mines north of town. In places it is from 200 to 300 yards [illegible]e. Near Seven Troughs it contains masses of obsidian or glass, [illegible]h suggest that this part of the dike must have cooled very near [illegible] surface. Farther north it has a rude columnar structure, the col[illegible]ns lying horizontally across the dike. It must be said that the [illegible]ification of the mass as a dike rests almost wholly upon its gen[illegible]l form and position. The possibility of its being a down-faulted [illegible]p from the mica andesite flows has not been eliminated.

The tuffs and arkosic sediments are very poorly exposed, and a [illegible] mine workings, as yet shallow, are the only places where any[illegible]ing can be learned of their attitude and structure. In some of [illegible]se the beds are nearly horizontal; in others they are tilted up to [illegible], the dip in the few openings where it could be observed accord[illegible]g generally with the anticlinal structure of the district. In the [illegible]es changes from tuff to basalt or rhyolite are common and often [illegible]plexing. This is due partly to the fact that the basalt occurs [illegible]th as flows and as irregular intrusions, partly to the local and [illegible]riable character of the different formations, and partly to faulting.

Associated with the basalt and tuffaceous deposits are masses of a [illegible]ght-yellowish rhyolite, which in the field, prior to petrographic [illegible]dy, was not readily distinguished from the younger mica andesite, [illegible]en thought to be also a rhyolite. It was supposed at the time of [illegible]it that the yellowish rhyolite might be a lower, slightly altered [illegible]art of the series of flows now known to be andesitic. It proves, [illegible]owever, to be a distinct and older rock. Whether it is extrusive [illegible]d rests generally on the tuffs or is intrusive into them is not yet [illegible]own. It is exposed in the bottom of Seven Troughs Canyon, just [illegible]west of the town, where it is apparently separated from the mica [illegible]ndesite by a basalt flow. The rock is compact and contains numer[illegible]s small phenocrysts of quartz, orthoclase (sanidine), and biotite. The microscope shows also a few phenocrysts of plagioclase. The groundmass is partly devitrified microlitic glass.

In general it must be said that in detail the structure of the dis[illegible]trict is obscure and complex; it will require much more than a recon[illegible]naissance examination for its satisfactory interpretation.

The Fortieth Parallel Survey map shows that a considerable part of the range in the vicinity of Aloha Peak, south of Seven Troughs, is covered by basalt. Dark scarps, presumably of this rock, are visible along the crest of the range from near Vernon, and bowlders of hard vesicular basalt are abundant in the wash near that town. This flow is probably younger than any of the rocks exposed near the mines.

DISTRIBUTION AND DEVELOPMENT OF THE MINES.

The most important group of mines is at Seven Troughs. Just southeast of the town, which lies on the south bank of the arroyo running down to Mazuma, are the Kindergarten and Wihuja mines, both on the same vein. The Kindergarten mine, owned by the Seven Troughs Kindergarten Mining Company, is developed by a tunnel and by an inclined shaft 280 feet deep on the dip. A new vertical shaft, being sunk at the time of visit in August, 1908, was expected to cut the vein at a depth of about 300 feet. The Wihuja is a lease on the ground of the Seven Troughs Therien Gold Mining Company, and is opened by an inclined shaft to a vertical depth of about 212 feet. The Kindergarten and Wihuja workings are connected. Other leases on Therien ground, in operation but not productive in 1908, were the Bard and Jess (175 feet deep), the Tyler, and the Sandifer leases.

On the north side of the canyon, close to town, are the Mazuma Hills and Reagan mines, both productive. The Mazuma Hills mine is owned and operated by the Mazuma Hills Mining Company; the Reagan is a lease on a vein lying east of the Mazuma Hills vein, but within the ground of that company.

The Mazuma Hills mine is opened by a main adit 700 feet long. Winzes from this adit connect with a level 100 feet below and about 500 feet long. There is also an upper disused adit about 100 feet above the main level. The Reagan is worked through a shaft that was 165 feet deep at the time of visit. Only the 65-foot level, however, could then be examined, the bottom level being temporarily under water, pending the installation of pumps.

South of the Mazuma Hills and Reagan mines is the Sandifer lease on Therien ground. Here, in the bottom of the canyon, a shaft is being sunk in expectation of finding ore in the southern parts of the Mazuma Hills and Reagan veins.

North of the Reagan shaft, on the same fissure zone, are the Chadbourne and Bradley leases, whose shafts are respectively 135 and 165 feet deep. Neither had been productive up to August, 1908. On the hillside a short distance above and north of the Mazuma Hills tunnels is the shaft of the Hayes-Mazuma lease. This was being sunk through rhyolite at the time of visit and was not in ore.

Between the workings mentioned and the head of the ravine north of Seven Troughs are the Eclipse shaft, Providence tunnel, and various smaller unproductive openings made by lessees and prospectors. On the north side of Seven Troughs Canyon, about a quarter of a mile below the town, is the tunnel of the Seven Troughs Tomboy Mining Company. This is a crosscut running N. 50° E. At the time of visit it was 800 feet long, and the intention of the company was to carry it 400 feet farther. The tunnel first penetrates about 50 feet of rhyolite and then goes through a seam of gouge into soft pyritized tuffaceous beds with a general low dip to the northeast. These are cut by many faults, probably of small throw, and contain some masses of basalt. About 350 feet from the portal the tunnel goes through another seam of gouge into rhyolitic (or possibly andesitic) breccia cut by dikes of glass or obsidian. Lower down the canyon, near Mazuma, considerable tunneling has been done on the Badger group of claims. These workings were not examined.

In Wildhorse Canyon prospecting was in progress in 1908 on the Wild Bull, North Pole, and other claims. The Wild Bull showed a little ore, but no shipments had been made.

North of this canyon the only active prospecting appeared to be on the Snow Squall claim in Victor Canyon, south of Farrell. It was reported that lessees had found good ore in sinking their shaft, but the workings were not visited.

From the saddle south of Seven Troughs a long ravine runs south and then turns southeast, embouching at Vernon. In the upper part of this ravine is the Dixie Queen shaft 230 feet deep and the Cleghorn Consolidated and Signal tunnels from 200 to 300 feet in length. Some lessees also were operating in 1908 on property of the Signal Peak Mining Company, high up on the ridge south of Seven Troughs, but owing to lack of time their shaft was not visited. About halfway down the canyon and about 2 miles south of Seven Troughs is the Fairview mine, reported at the time of visit to be 650 feet deep. This mine is known to have had some bunches of very rich ore in the upper levels and is said to have shipped about $65,000. No stoping was in progress at the time of visit and the shaft was being carried down through hard basalt. The mine is owned by practically the same people that control the Kindergarten and Therien properties at Seven Troughs. In contrast to the attitude of other mine owners in the district they showed disinclination to impart information and refused access to the Fairview mine.

Adjoining the Fairview workings on the north is the Harris lease, on Fairview ground, with a shaft 185 feet deep. The dump is basalt, much of it being vesicular.

There were two mills in operation in the latter part of 1908, one belonging to the Kindergarten company and situated at Seven

Troughs, the other belonging to the Mazuma Hills company and situated at Mazuma. Both are 10-stamp mills with amalgamating plates, Wilfleys, and vanners. No attempt is made to cyanide the tailings or save them.

CHARACTER OF THE DEPOSITS.

Most of the dikes and fissures near Seven Troughs have a nearly north-south trend. The veins as a whole consist of soft, crushed material and do not outcrop above the surface. They represent zones of brecciation or of small fissures, along which movement has continued since the spaces originally formed were filled with quartz. Consequently the typical quartz of the district is friable or sugary, and generally contains or is mingled with many fragments of shattered rock. Clear solid masses of quartz, even of small size, are rare. The veins on the whole are rather narrow, ranging from a few inches up to about 2 feet in width. It is possible, however, that the average working width may be considerably increased when the district has better facilities for handling and treating ore.

The valuable constituent of the lodes is native gold containing a considerable proportion of silver, and consequently of a rather pale color. In most of the rich ore the gold is visible either as clusters of small irregular particles or as coarse crystalline aggregates. No complete well-formed crystals were seen, but there is a noticeable tendency of the coarser gold to form crystal facets. The Mazuma Hills, Reagan, and Fairview mines have afforded some very showy specimens of bright yellow gold interlaminated with firm quartz or enveloping fragments of altered country rock. Loose nugget-like masses up to an ounce in weight have been found in soft crushed vein matter in the Reagan lease. The rich bunches of gold are not uniformly distributed through the veins, and it is difficult in some cases to secure clean sorting. It was found, for example, that material thrown over the Reagan dump as waste or as low-grade ore to be treated later carried small quartz stringers, and that some of these, when broken across, contained coarse native gold.

The tenor of the ores, as is to be expected, has a wide range. A mill run from the Reagan lease in August, 1908, averaged about $130 a ton. Picked ore from the Fairview, Mazuma Hills, and Reagan mines has yielded at the rate of several thousand dollars a ton. In the Kindergarten mine the ratio of gold to silver by weight is said to vary from 1: 2 to 1: 3 near the surface, but at the bottom of the mine to be nearly 1: 1. Assay certificates of rich ore from the Reagan lease, seen in Seven Troughs, showed a ratio of nearly 2 of gold to 1 of silver. At one place on the lower level of the Mazuma Hills mine quartz carrying a little chalcopyrite is reported to have yielded on assay 200 ounces of silver and 0.3 ounce of gold to the ton.

The three important veins near Seven Troughs are the Mazuma Hills, Reagan, and Kindergarten veins. The first two, known only on the north side of the canyon, strike about N. 10° E. and dip from [illegible]5° to 65° W. The Reagan vein lies about 40 feet east of the Mazuma Hills vein. The Kindergarten vein, on the south side of the canyon, strikes N. 63° E. and dips south. The dip varies from 60° near the surface to 22° on some parts of the 40-foot level. The dip at the bottom level is about 35° (vertical depth 212 feet). The stope length of the ore shoot is about 130 feet, and the average workable width of ore is probably about 2 feet. At the northeast end of the mine the vein appears to be cut off by a zone of north-south fissures in which no ore had been found at the time of visit.

The country rock varies from place to place in each mine. The Kindergarten and Wihuja workings, as seen in 1908, are mainly in basalt. Part of this is a soft, altered amygdaloidal variety, evidently an extrusive rock. Other parts are a dense, olivinitic variety that apparently cuts the amygdaloidal flow rock. Masses of soft, light-colored rock, either rhyolite or mica andesite, but too decomposed as a rule for satisfactory determination, occur at unexpected places on both sides of the vein. They probably represent intrusions more or less displaced by faulting.

The Mazuma Hills vein follows a basalt dike that varies in width from a fraction of an inch to more than 6 feet. The general country rock is a nearly white altered rock that the microscope shows to have been originally a highly glassy rhyolitic tuff or flow breccia. It is now devitrified into a fine-grained, obscurely crystalline aggregate and contains minute disseminated crystals of pyrite. The best ore is on the foot wall or east side of the dike, and appears to be for the most part minutely fissured and silicified rhyolite tuff; but some ore extends into the basalt. At one place there is a second vein, about 10 feet east of the main fissure zone and with a little lower dip. The horse of rhyolite tuff between the two is said to be all low-grade ore. Some of the best ore in the mine is reported to occur as small gold-bearing stringers traversing hard rhyolitic tuff.

The Reagan vein also follows a basaltic dike and shows considerable resemblance to the Mazuma Hills vein. The general country rock, however, is more varied. Much of it is a highly-altered volcanic glass, apparently basaltic, which owing to its originally brittle character, has been elaborately and minutely cracked and fissured. Many of the cracks are microscopic and have a perlitic arrangement. This rock is generally greenish gray, and much of it is so fine grained that its mineralogical character can not be ascertained under the microscope. Other varieties show a few microscopic phenocrysts of plagioclase, partly altered to calcite, and a groundmass in which [illegible]
an original [illegible]

of the Reagan lease consists of this altered basaltic glass, in which the irregular cracks have been filled with quartz carrying free gold. The secondary minerals identified in the glass itself are pyrite, quartz, calcite, and apparently a little chlorite. Calcite is not abundant, which is rather surprising in view of the calcic composition of basalt. In some places altered glass of the kind described passes into a highly amygdaloidal variety that is well exposed in a tunnel on the Sandifer lease just south of the Reagan mine and in the Bradley lease to the north. In the Sandifer lease the vesicles are only partly filled by clear projecting crystals of quartz. In the Bradley lease some are filled with quartz and some with calcite. Pyrite is disseminated through the light greenish gray altered substance of both varieties, and a few vesicles were noted that were first lined with pyrite and then filled with quartz. Although pyrite is fairly abundant throughout the altered basaltic and tuffaceous rocks near the ores, and occurs with quartz in very small, almost microscopic veinlets, it appears to be rare in the generally larger veinlets in which are the visible particles of gold. These veinlets, so far as could be seen in 1908, contain little or no pyrite. According to Mr. D. H. Skea,[a] some proustite and possibly some stephanite or polybasite were found with the gold in the Fairview mine, and a little chalcopyrite and specks of a gray mineral resembling bornite were noted in 1908 on the bottom level of the Mazuma Hills mine in quartz similar to that elsewhere rich in gold; but as a rule the auriferous quartz is notably free from any other mineral than gold. Stibnite occurs in friable lenticular masses of considerable size in soft crushed basalt in the Chadbourne lease, and is said to have been found also in the Reagan lease. It does not, however, appear to have any intimate connection with rich ore. A little native silver is said to have been panned from the ore of the Wild Bull mine in Wildhorse Canyon.

All of the ore visible in 1908 was within the range of oxidation. The results of weathering, however, owing to the very small quantity of pyrite in the veinlets, are not conspicuous, and there appears to be no very definite change from oxidized to sulphide ores. Pyrite and stibnite, as has been seen, both occur in connection with the ore deposits above the ground-water level. The surface of the underground water near Seven Troughs corresponds approximately to the bottom of the canyon, in which is some running water, and doubtless rises a little higher in the adjacent ridges. In August, 1908, water was just making its appearance in the bottom of the Kindergarten mine at a depth of 212 feet, and the lessees of the Reagan, 165 feet deep, were putting in a pump in order to work their lower level.

[a] Oral communication.

OUTLOOK FOR THE DISTRICT.

Not enough mining or geologic work has been done to enable anyone to pass final judgment on the future of the Seven Troughs district. The presence of very rich, easily treated gold-silver ore in fair abundance at several places within an area some 6 miles in length is highly encouraging. On the other hand, it should be noted that the veins are not of great size and apparently are not as a rule of great length or persistence, and their character at any considerable depth below possible superficial enrichment is yet undetermined. Moreover, it is evident that in most of the mines the country rock may be expected to differ at various depths, and it is yet to be proved that the rocks beneath the tuffs and basalt in which most of the known ore occurs will be equally productive. In short, while the district is a most promising one for prospecting and developing, it is yet too early to regard it as one certain to yield largely for a period of many years.

ROSEBUD DISTRICT.

SITUATION AND HISTORY.

The Rosebud district is situated in the Kamma Mountains, a minor crescentic ridge lying north of the Seven Troughs Mountains and fronting with its concave northwest side the forbidding expanse of the Black Rock Desert. The main summits rise from 2,000 to 3,000 feet above the desert. Like the Seven Troughs Mountains, the group is merely a part of the Trinity Range. The town of Rosebud, close to which the mines are situated, is about 28 miles northwest of Humboldt House, a station on the main line of the Southern Pacific Railroad, and about 35 miles from Mill City. There is a stage from Humboldt House about once a week, but in September, 1908, no attempt was being made to maintain a regular schedule.

The Kamma Mountains have long been known as a source of sulphur, the Rabbit Hole sulphur mine having been worked since 1874. This deposit, which has been described by G. I. Adams,[a] is about 5 miles north-northeast of Rosebud and was not visited in the course of the present reconnaissance.

Silver ore appears to have been first discovered near the site of Rosebud in 1906. This was followed by a senseless "boom," in which, as usual, folly played eagerly into the hands of fraud. Consequently, the town, which sprang up before the existence of any considerable body of ore was assured, is now nearly deserted, and the winds whistle through the unglazed windows of its most pretentious buildings, abandoned before completion.

[a] The Rabbit Hole sulphur mines near Humboldt House, Nevada: Bull. U. S. Geol. Survey No. 225, 1904, pp. 497-500.

A year or two ago the Brown Palace mine shipped from 15 to 20 tons of ore from an open cut about 10 feet deep. This, so far as known, represents the total output of the district up to the end of 1908. Some prospecting and development were in progress in September of that year, and it is possible that with the opening of the Western Pacific Railroad, which passes a few miles north of Rosebud, the district may ultimately prove of some importance.

GENERAL GEOLOGY.

According to the Fortieth Parallel Survey map, the oldest rocks in the Kamma Mountains are Triassic and are exposed in the southwest part of the range, associated with a little dacite and diorite. About Lander Spring, on the east side of the range, is shown an area of Jurassic rocks overlain to the west by rhyolite and andesite that are probably Tertiary. The supposed Jurassic slates are the prevailing rocks seen on the road from Humboldt House to Rosebud, which crosses the Trinity Range north of Antelope Peak, by way of Willow Spring. The veins worked at Rosebud are all in the rhyolite, which occurs as laminated flows and flow breccias. These rocks form rounded hills, rising about 1,500 feet above the town. The rhyolite is not conspicuously porphyritic and as a rule is very fine grained. Most of it represents an originally glassy rock that has undergone devitrification and locally a good deal of secondary alteration—chiefly silicification, with the development of some sericite, kaolin, and pyrite.

ORE DEPOSITS.

The principal zone of mineralization lies about half a mile north of Rosebud and strikes nearly east and west. At the west end of the zone is the White Alps property, on which some lessees have an inclined shaft 130 feet deep on a belt of fissuring and alteration that dips 70° N. There is very little vein quartz, and that merely in the form of small irregular stringers. The mineralized material is a white, much-altered rhyolite containing abundant finely disseminated pyrite which here and there gathers into small bunches. The individual crystals are as a rule almost microscopic. The soft white material into which the rock is largely altered and in which the pyrite is embedded is kaolinite. The deposit appears to have no definite walls and is generally of low grade. A little $50 ore has been found near the surface.

East of the White Alps, on the same general zone of fissuring and alteration, is the Brown Palace mine. Here two tunnels, one 300 feet and the other about 500 feet long, have been run into the hill on opposite sides of a small spur. No ore has been found in them. Higher up the hill is a small open cut on the fissure zone, whence was obtained

the only ore shipped from the district. This occurred as a mass of 15 to 20 tons, in which the valuable constituent was massive argentite associated with kaolin, limonite, yellow pulverulent jarosite, and more or less oxidized rhyolitic material. This ore was found at a place where a little north-south fissure with a low dip to the west joined the main fissure zone on its south side. The ore rested on the foot wall of the minor fissure and did not extend over 10 feet from the surface.

East of the Brown Palace ground is the Dreamland, with a 100-foot vertical shaft and short drifts on two levels. The vein strikes N. 70° E. and is about vertical. It consists of hard, dull-white cryptocrystalline quartz in pyritized rhyolitic flow breccia. Its maximum width is 1 foot, but it is irregular, splits at some places into stringers, and apparently is not very persistent. The quartz contains more or less disseminated argentite, and a little ore has been sorted and saved for shipment.

There are a few other prospects in the district at which work was in progress at one time or another in 1908, including the Golden Anchor east of the Dreamland. These, however, were not examined.

Although the rocks of the Rosebud district have evidently been subjected to the action of solutions similar to those that elsewhere have produced important deposits of the precious metals, it is not yet apparent that any large or persistent veins have here been formed. The little ore thus far discovered is so near the surface and is of such a character that it can not be regarded as indicating deep and important ore bodies, although the possible existence of these is not denied.

RED BUTTE DISTRICT.

SITUATION AND HISTORY.

The small settlement of Red Butte, which consisted in September, 1908, of about 30 tents, is situated 45 miles north-northwest of Humboldt House, 55 miles a little north of west from Winnemucca, and 30 miles north of Rosebud. It lies near the south end and on the west slope of a rugged ridge, locally known as the Jackson Range, but really connected by a broad belt of lower hills with the Trinity Range to the south. There is no regular stage to Red Butte, but the district may be reached by hired conveyance from Humboldt House or Mill City. The camp is attractively situated close to a flowing spring, on a gentle slope backed by the dark, partly wooded peaks of the Jackson Range and fronting westward on the vast gleaming expanse of the Black Rock Desert, broken here and there by lonely buttes whose strange and sharply carved forms glow with the ethereal colors of a desert landscape.

The Red Butte district was opened by Mr. A. D. Ramel in May, 1907, his first prospecting being for gold on the Redeemer claim about a mile north of the present settlement. Since then work has been directed mainly to the exploration of the various copper deposits presently to be described. No ore has been shipped, and underground exploration at the time of visit was confined to openings of a very superficial character made for the most part by the original locators of the claims. The quiet prospecting here in progress is very different from the methods that gave notoriety to Rosebud.

GENERAL GEOLOGY.

For over 15 miles north of Humboldt House the road keeps to the middle of a wide, deeply filled desert valley. It then turns northwestward and crosses obliquely a broad, low part of the Trinity Range composed principally of dark slates mapped as Jurassic by the geologists of the Fortieth Parallel Survey [a] from their lithologic resemblance to the Mariposa slate of California and to slates overlying Jurassic limestone in the Humboldt Range. The grade for the Western Pacific Railroad has now been carried through these hills, and the slates have been well exposed in numerous deep cuts, which, however, there was no opportunity to examine on this trip.

From these slate hills the ragged pinnacles of the Jackson Range, which appear to rise 2,000 to 3,000 feet above Black Rock Desert, are conspicuous to the north. They are composed, so far as could be judged from an examination of their lower slopes and from material brought down by streams, of a hornblendic and hypersthenic gabbro, which also is the prevailing rock of the Red Butte district. The gabbro and related igneous rocks are probably intrusive into the slates, but no exposure of the contact was seen in the few hours spent in the district. Some stratified rock, reported to be limestone, is visible from the camp in a subordinate ridge along the edge of Black Rock Desert, a few miles to the northwest.

The most abundant gabbroitic rock near Red Butte is dark gray, medium grained, and evidently rich in hornblende. The microscope shows it to consist of a hypidiomorphic-granular aggregate of labradorite, hornblende, augite, quartz, magnetite, and apatite. The hornblende appears to be in part primary, but in part also it has been derived from the augite. Most of the quartz is an original constituent, and fills angular interstices between the feldspar crystals. This rock as a rule is more or less altered and contains quartz, sericite, chlorite, and a little epidote derived from the other minerals. A more coarsely crystalline variety of lighter color was noted about 1 mile north of the camp. This contains crystals (poikilitic anhedrons)

[a] Described in vol. 2, 1877, pp. 755-756.

of hornblende up to 2 centimeters in length. Under the microscope the rock is seen to be composed of calcic labradorite, augite, hypersthene, biotite, quartz, and much hornblende. The last is in part sharply intergrown with the pyroxenes, but a considerable proportion of it appears to have been formed by the alteration of the colorless augite.

Detailed petrographic study would doubtless reveal other varieties of basic igneous rocks, but for the purposes of this reconnaissance the general country rock of the district is designated with sufficient accuracy as gabbro.

Cutting the gabbro are numerous dikes of a light-gray to pink aplitic rock that contains practically no dark or femic constituents. These dikes vary greatly in size and trend, and some of them are very irregular, as may be seen on Anaconda Ridge just southwest of the settlement. The contacts between the dikes and the gabbro, as exposed on this ridge, are close and distinct, but careful inspection shows that between the two rocks there is generally a gradational zone, less than an inch in width. Along some of the larger dikes the zone is wider, and this suggested at first glance that the dikes were merely belts of alteration in the gabbro. The dikes probably were injected while the gabbro mass was still at a high temperature, so that instead of a rapid chilling of the dike magma at its bounding walls there was a slight interpenetration and mixture of dike material and gabbro. This feature is not uncommon where granitic rocks are cut by the aplitic dikes characteristically associated with siliceous plutonic intrusives.

Microscopical study shows the pinkish dike rock to consist of alkalic feldspars with some sodic oligoclase and considerable interstitial quartz. In some varieties the quartz and feldspar are intergrown as micropegmatite. Most of the alkalic feldspars are twinned repeatedly and irregularly according to the albite and pericline laws, and are intergrowths of both the albite and orthoclase molecules. Specific determination of them was not attempted.

A considerable part of Anaconda Ridge, about 2 miles southwest of Red Butte camp, is composed of a compact, minutely porphyritic, dark-gray rock, which the microscope shows to be a slightly altered andesite. Presumably this rests on or is intruded by the gabbro, but its structural relations were not ascertained. Some basaltic rocks also were noted along the road a few miles south of the camp, between the gabbro and the slates, but they were not closely examined. One kind of these is remarkable for the large size of the plagioclase phenocrysts, which are tabular parallel to the brachypinacoid and up to $1\frac{1}{2}$ inches (4 centimeters) in length.

COPPER DEPOSITS.

The copper deposits at Red Butte are closely associated with the aplitic dikes. A few only of the more important prospects could be examined. At the Copper Queen and Metallic groups of claims, about 1½ miles southeast of the camp, a short tunnel and a few shallow pits have been opened on some bunches of oxidized ore containing cuprite, covellite, native copper, and chrysocolla, associated with hematite, limonite, and a little barite. The ore is rather irregularly distributed through a fine-grained aplitic dike, which in part is altered to a rusty jaspery material. Not enough work has been done to reveal the extent and trend of the ore. The general course of the dike with which it is associated appears to be nearly northwest and southeast. Whether the ore occurs throughout the dike or is confined to its sides, near the gabbro, was not clear from the exposures available at the time of visit. The openings also gave no clue to the original mineralogical character of the ore before its oxidation.

The Anaconda prospect, situated on the ridge of the same name, about a mile southwest of the camp and 400 to 500 feet higher, was being developed at the time of visit by open cuts. The workings are entirely within a broad north-south aplitic dike, which cuts fairly coarse gabbro. The valuable constituent here is native copper, which occurs along narrow seams and joints in the dike rock and is to some extent disseminated through it. Work had just begun and the extent of the ore body had not been ascertained. The rock in which the native copper occurs is not much altered and no quartz or other vein material is present.

At the Redeemer claim, about a mile north of the settlement, a fissure zone in the gabbro carries streaks of chalcocite partly altered to chrysocolla, malachite, and azurite.

Not enough prospecting has yet been done to determine the importance of the district as a source of copper. The superficial aspect of the deposits does not, however, suggest great size or richness.

Another belt of mineralization, not visited, is said to skirt the east base of the Jackson Range and to carry copper and antimony. At one place, a few miles southeast of Red Butte, some work was in progress at an antimony prospect in September, 1908, and it was reported that a shipment of partly oxidized stibnite would soon be made. Cinnabar also occurs a few miles southwest of Red Butte, west of the road to Rosebud. The deposit has been very little developed and was not examined by me.

HUMBOLDT RANGE.

GENERAL GEOLOGY.

The Humboldt Range (see Pl. I) has a total length of about 75 miles and attains a maximum altitude, in Star Peak, of nearly 10,000 feet. As all who have written about the range have recognized, it is divisible into two distinct parts, separated by a fault the position of which is marked by a low transverse pass known as Cole Canyon. The northern division, called by Louderback[a] the Star Peak Range, trends north and south and is about 32 miles long. The southern part, called by the same writer the Humboldt Lake Range, trends north-northeast and south-southwest and is over 40 miles long. The course of Cole Canyon is north-northwest.

According to Hague[b] the Humboldt Range consists of an Archean nucleus upon which rest Triassic strata of great aggregate thickness. These are overlain by Jurassic beds. There are also, on the lower slope, considerable masses of Tertiary rhyolite and basalt and a few rather small exposures of Miocene beds belonging to the Truckee formation.

When it is remembered that the geologists of the Fortieth Parallel Survey mapped an enormous area, that many of their lithologic determinations necessarily depended upon the color and erosional forms of rocks as seen from some commanding point of view, that their geologic field work was done before the topographic maps were available, and that the science of microscopical petrography was then in its infancy, no surprise need be felt that many and important changes must be made in their mapping by those who follow in their footsteps. Louderback[c] has shown that the so-called Archean nucleus, exposed in Rocky Canyon, southeast of Ryepatch, consists of a mass of post-Triassic intrusive granite with associated contact-metamorphic rocks. The intrusion, as Louderback observes, probably took place during the period of post-Jurassic deformation that affected the Great Basin region and the Sierra Nevada.

The Triassic rocks were divided by Hague into two formations. The upper or Star Peak formation is described as consisting of the following, numbered from the base up:

Tabular section of the Star Peak formation compiled from the description by Arnold Hague.

	Feet.
5. Quartzite and overlying limestone	4,000–5,000
4. Massive limestone	1,800–2,000
3. Black arenaceous slates	200–300
2. Slaty quartzites alternating with greenish schistose rocks	1,500
1. Limestones. Dark, almost black at the base, passing up into gray and blue varieties	1,200–1,500

[a] Basin range structure of the Humboldt region: Bull. Geol. Soc. America, vol. 15, 1904, p. 294.

[b] Descriptive geology, U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 714.

[c] Louderback, G. D., Basin structure of the Humboldt region: Bull. Geol. Soc. America, vol. 15, 1904, p. 318.

The total thickness is roughly estimated by Hague at 10,000 feet.

The Star Peak formation is noted for its abundant Middle Triassic vertebrate and invertebrate fossils, which have been described by Gabb,[a] Meek,[b] Hyatt and Smith,[c] and J. C. Merriam.[d] The stratigraphic section, however, is much in need of detailed study. Less hurried work will, I believe, make considerable changes in the sequence and lithology as interpreted by Hague and is likely to show some duplication of units in his section. Hyatt and Smith[e] state that the Upper Triassic is also represented in the Humboldt Range and list half a dozen fossils. The beds containing them are said to be unconformably overlain by limestone containing Jurassic forms.

The lower division of the Triassic was called by Hague[f] the Koipato formation, from the Indian name of the Humboldt Range. It is described as a series of quartzites and "porphyroids," with a total thickness roughly estimated at 6,000 feet. The "porphyroids," although recognized as closely resembling eruptive rocks, were regarded by Hague as "metamorphic products of the mixed quartz and feldspar rocks of the series of beds underlying the limestone of the Star Peak Triassic."

In the light of modern petrographic knowledge, Hague's descriptions and the accompanying chemical analyses of the "porphyroids" strongly suggest that they are not metamorphosed sediments, but are for the most part eruptive rocks. The exigencies of a hasty reconnaissance did not permit a thorough examination of the Koipato formation in 1908. Enough of it was seen, however, to leave no doubt of its dominantly igneous character. It consists of volcanic flows, mostly rhyolitic but including also andesitic lavas, associated with tuffs, conglomerates, grits, and limestones. The "porphyroids" are for the most part true igneous porphyries, although some of the tuffs may also have been included under this designation. As is to be expected in pre-Tertiary lavas that have been subjected to considerable deformation, the originally more or less glassy rocks are devitrified and altered, in some places even to being rendered rudely schistose. The extrusive and tuffaceous rocks are cut by rhyolitic and dioritic dikes that are also of early Mesozoic age, and the Koipato formation as a whole is a volcanic complex, of which nonvolcanic sediments, including limestones, form a subordinate part. No true quartzite was observed in the Koipato in the course of this reconnaissance.

[a] Paleontology, vol. 1, Geol. Survey California, 1864, pp. 19–35.
[b] Paleontology, U. S. Geol. Expl. 40th Par., vol. 4, pt. 1, 1877, pp. 99–129, Pls. X and XI.
[c] Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 21–23, Pls. XXII–XXV.
[d] Triassic Ichthyosauria: Mem. Univ. California, vol. 1, No. 1, Berkeley, Cal., 1908, pp. 18–19.
[e] Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, p. 26.
[f] Op. cit., p. 716.

Hague calls attention to the fact that the division of the Star Peak formation that I have numbered 2 on page 31 is very similar to the Koipato formation. An examination of these rocks near the Sheba mine, in Star Canyon, shows that they comprise andesitic and rhyolitic flows and tuffs, with some beds of tuffaceous grit and of limestone. All are altered and are slightly schistose parallel with the bedding planes. Were it not that these rocks appear to be underlain by a considerable thickness of black shaly limestone they would naturally be grouped with the Koipato. As it is, their stratigraphic position is a little doubtful. The plane of division between the Koipato and Star Peak formations is much in need of close study and accurate definition.

The structure of the Humboldt Lake Range has been carefully studied by Louderback,[a] who reached the conclusion that it is a block of folded pre-Cretaceous rocks elevated and tilted to the east in late Tertiary time by a zone of faults along the west front of the range. His explanation of the structure of the Star Peak Range is similar, and he believes that the main fault along the west base of this range curves to the east through Cole Canyon and has thus effected the separation of the Humboldt Range into its two distinct divisions.

The Humboldt Lake Range contains no important mines, and no examination of it was made during this reconnaissance. The older structure of the Star Peak Range was found to be broadly anticlinal as described by Hague, the axis of the fold trending north-northeastward from Cole Pass and thus crossing the range obliquely. From Cole Pass to Unionville is a belt of Koipato rocks 7 to 8 miles in breadth. Southeast of it is the Buffalo Peak mass of the Star Peak formation. Northwest of the Koipato belt the main ridge, from a point southwest of Unionville to the valley of the Humboldt near Mill City, is also made up of the Star Peak formation, overlain in the vicinity of Humboldt House by Jurassic strata. Thus the northern half of the Star Peak Range has the structure of a monocline dipping a little north of west. If faulting along the west base of the range, as deduced by Louderback, actually occurred, the consequent eastward tilting of the whole mountain block must have decreased by so much the dip of the older monocline, which is still the most conspicuous structural feature of this part of the range.

HUMBOLDT QUEEN MINE.

The Humboldt Queen mine is situated 5 miles northeast of Oreana, a now little-used station on the Southern Pacific Railroad, and is be-

[a] Op. cit.

tween the mouths of Sacramento and Limerick[a] canyons, at the west base of the Star Peak Range.

Little has been ascertained relating to the history of this mine. It is known to have been in operation in 1883, and the aspect of the empty buildings indicates that some work has been done during the past two or three years. No statement of the total production was obtained.

The general country rock of the mine is thin-bedded limestone, mapped by Hague as part of the Star Peak formation. It forms at this place a narrow north-south belt, bounded on the west by the sediments of Lake Lahontan and recent alluvium and on the east by granite porphyry or rhyolite porphyry, which on the Fortieth Parallel Survey map is included with the Koipato formation. The belt as exposed is from one-third to one-half mile wide and appears on the Fortieth Parallel Survey map as the narrow southernmost point of the area of the Star Peak formation that farther north makes up most of the range. The limestone beds are thrown into sharp complex folds trending generally about N. 10° E. A few of the folds are overturned, as illustrated in figure 2. Some beds are not noticeably metamorphosed, but others, especially the shaly ones, show considerable alteration, needles of tourmaline and rosettes of a dark-green mineral probably belonging to the chlorite group being noticed in some loose masses that had rolled down from the slope east of the mine. The limestone is cut by a north-south dioritic dike, in places several hundred feet wide, which passes a short distance east of the mine workings. The metamorphism may be due to the intrusion of this rock.

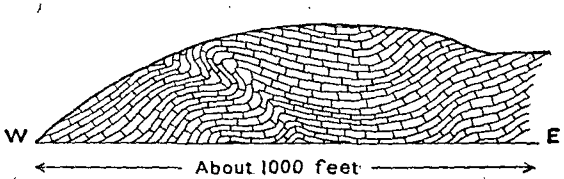

FIGURE 2.—Sketch of folded limestone as exposed on the slope of a small hill north of the Humboldt Queen mine.

The Humboldt Queen mine comprises numerous openings along a section, 1,000 feet or more in length, of a complex north-south zone of veins in the limestone. The workings are mostly tunnels and shallow shafts or pits. At the south end of the explored zone, however, is an old inclined shaft from which most of the stoping appears to have been done, and just south of it a newer vertical shaft, apparently 200 feet or more in depth.

The veins are generally parallel with the bedding of the limestone and are sharply folded with that rock. In a few places they cut across the beds, but this appears to be exceptional. The consequence

[a] On the Fortieth Parallel Survey maps the name Sacramento is applied to the canyon up which passes the road from Humboldt River to Fitting or Spring Valley. This is now locally known as Limerick Canyon, the one north of it being called Sacramento Canyon.

of this conformity with the bedding is much variation in dip and strike, and of course the failure of some veins or parts of veins to extend to great depth. In some places the veins are horizontal, in others they are vertical, and the change in dip or strike is in many instances very abrupt, as may be seen from figure 3, in which some of the structural eccentricities of these veins are diagrammatically illustrated. At the collar of the old inclined shaft the vein stoped dips 55° E., but at a depth of 30 feet it curves and a short distance below it dips 60° to 70° W.

The topography of the vein zone is irregularly hilly, and as the intricate folding may bring the same vein to the surface at many places, it is impossible to say without detailed study how many bed

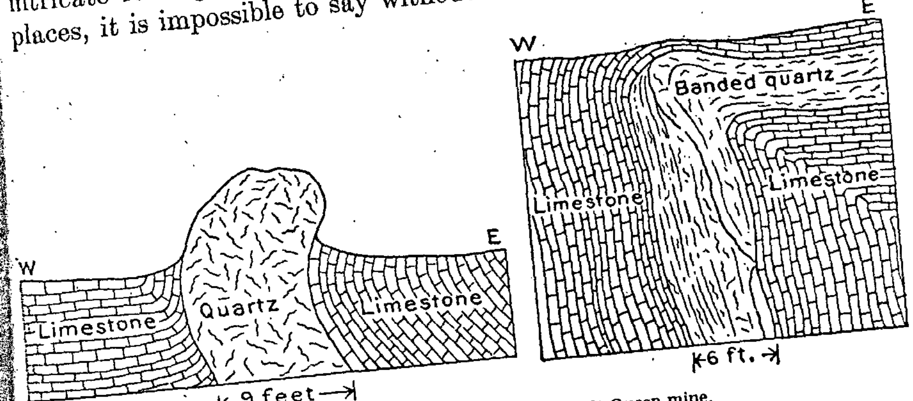

FIGURE 3.—Structural details at the Humboldt Queen mine.

veins there are in the belt. There appear, however, to be more than one.

The vein faces exposed show various widths up to about 10 feet. The filling is milk-white quartz, which in most places is banded parallel with the wall by thin dark seams of argillaceous material. The spaces now occupied by the veins were probably opened gradually, with successive deposition of quartz after each movement. Some of the folding appears to have taken place before all of the quartz was deposited, but much of the deformation is later than the veining, as the quartz is generally shattered, although not thoroughly crushed, and the banding of the quartz conforms as a rule to the folds. Other minerals noted in association with the quartz are calcite, pyrite, galena, sphalerite, and tetrahedrite.

FITTING AND AMERICAN CANYON.

The limestone belt in which is the Humboldt Queen mine terminates at Limerick Canyon. For about half a mile from its mouth this canyon is cut in the granite porphyry already referred to as lying east of the limestone. This rock was not closely examined, but has the appearance of an intrusive mass. East of it the road over Spring Valley Pass crosses for more than 6 miles the main belt of the Koipato formation, which here appears to be composed mainly of dark-weathering siliceous porphyries. The belt is probably wider than as shown on the Fortieth Parallel Survey map, which represents the spurs between American Canyon and Fitting as composed of the Star Peak formation, whereas they appear to be made up largely of Koipato volcanic rocks, angular conglomerates, and tuffaceous grits. The lower ends of these spurs are capped by basalt, which is not shown on the Fortieth Parallel Survey map.

Fitting, still better known by its old name of Spring Valley, and the settlement of American Canyon, about 2 miles to the south, were flourishing placer camps in the early eighties. The only lode mine of importance is the Bonanza King, situated about half a mile south of Fitting. This mine, formerly known as the Eagle, shipped ore to San Francisco at least as early as 1884 and milled the lower grades at Mill City. Afterward a 15-stamp amalgamating and concentrating mill was built at Fitting, but this was not successful. The mine was worked by a lessee in the winter of 1907–8, but was idle at the time of visit.

The workings comprise a vertical shaft 300 feet deep, with levels 300 to 400 feet long and of generally rectilinear plan. The 125-foot level was the only one examined, as the upper ones are stoped to the surface and the lower ones are under water.

The vein strikes generally N. 60° W. and dips 82° SW. It follows an altered dioritic dike, which is about 45 feet wide. This cuts the rocks of the Koipato formation, represented, in the part of the workings examined, by a porphyritic rhyolite. Other rocks noted in the vicinity of the mine, and probably cut at various depths by the dike and vein, are rather angular conglomerates, grits, and tuffaceous beds, all containing much rhyolitic material and some limestone.

The vein consists of firm banded quartz and is generally within the diorite, separated by a thin slab of that rock from the foot wall of the dike. The old stopes, now open to the surface, are 5 to 6 feet wide, with smooth regular walls. On the 125-foot level the stopes are in some places 8 feet wide. A notable feature of the vein is its displacement by cross faults, of which five or six are known in the workings. These strike nearly northeast, dip southeast, and have normal throws. The maximum offset effected by any of these faults is about 35 feet. They cut the vein sharply and contain some crushed vein matter and ore.

The ore is reported to have ranged up to $400 a ton, with a varying ratio of gold to silver. It is not susceptible to treatment in the

present mill, and the lessee stated that in 1907 he was able to recover by milling only $8 a ton on what the smelter returns showed to be $80 ore. The ordinary ore shows galena, pyrite, and sphalerite in milky translucent quartz, which in some places is slightly stained with copper carbonates. The richest ore contains in addition argentiferous tetrahedrite.

The placer deposits in Spring Valley are no longer worked. In American Canyon, however, about a dozen white people are living in the former Chinese village, and the gravels are being explored by two or three new shafts. For a distance of fully 2 miles from its mouth American Canyon shows signs of former activity in hundreds of pits amid piles of gravel. These pits are all that remain of the Chinese shafts, which were very small and ranged from 40 to 100 feet in depth. As little timber as possible was used, and after the productive gravel layers had been worked by drifting for short distances from a shaft it was abandoned and a new one was sunk. According to Mr. W. G. Adamson[a] the pay streaks were found at depths of about 40, 60, and 85 feet. The total alluvial deposit in the canyon is in places much thicker, the Midas shaft, put down some years ago, being reported to be 200 feet deep and all in gravels and clays. No gold, so far as known, has ever been taken from the bed-rock surface in the bottom of the canyon, although this appears to have been reached in one of the newer shafts estimated to be about 100 feet deep. The gold is said to have been found mainly at the bottom of gravel layers, underlain by seams of clay. The gravel shows little rounding and apparently is subangular and imperfectly assorted wash from the adjacent hills.

According to Mr. Adamson, particles of cinnabar were often found with the gold in the rockers, and some good-sized bowlders of this mineral are said to have been taken from the gravels. This led to prospecting for cinnabar lodes, and some development work has been done at two places on the north side of the canyon. The only one of these visited is 2 or 3 miles from the mouth of the canyon, upstream from the placer ground. The deposit is a soft, crushed, kaolinized zone in porphyritic rhyolite. No walls are exposed and the zone is at least 6 feet wide. It dips north into the hill at 15° to 20°. Little specks of cinnabar are scattered through the kaolin, but no ore has been found, although an incline 200 feet long has been sunk and considerable drifting done.

The second deposit, said to be more promising, is a short distance north of the settlement of American Canyon, in limestone, with some eruptive rock forming the hanging wall. The vein is said to strike northwest and to dip 20° SW. Specimens shown me by Mr.

[a] Oral communication.

Adamson contained abundant cinnabar in small irregular fissures in dark-gray limestone. The vein is said to have been traced for a length of 3,500 feet and to have been opened to a maximum depth of 150 feet.

UNIONVILLE AND VICINITY.

Unionville is situated on the east slope of the Star Peak Range, in Buena Vista Canyon. It is about 10 miles north of Fitting and 15 miles south of Mill City. Although no longer a bustling mining town, the quiet little settlement, with its running water, shade trees, orchards, and gardens, possesses charms that are the more pleasing because unlooked for in so generally arid a region.

The principal mines are a mile or two southwest of Unionville and at least 1,000 feet higher up the range. The rocks in the vicinity of the town and exposed along the road up to the mines belong to the Koipato formation and are conglomerates, grits, and limestones, with much siliceous porphyry, most of it probably rhyolite. The igneous rocks appear to occur both as flows and intrusions, but no careful examination of them could be made in the time available. The topmost member of the Koipato seen on the road to the mines is a sheet of porphyritic rhyolite apparently a few hundred feet thick. This rock is considerably silicified and extremely hard. In most places it shows flow banding, which, while more or less contorted, conforms generally to the dip of the mass as a whole and to the beds above and below it. In places, also, the rock is spherulitic and the microscope shows that it is a partly altered, originally glassy rhyolite flow. Much rock of this character appears to have been mistaken for quartzite by the Fortieth Parallel Survey geologists from the fact that its outcrops, seen from a distance, have some resemblance to that material. Overlying this rhyolite flow are thin-bedded, fossiliferous Middle Triassic (Star Peak) limestones, and it is in these that the ore bodies occur. Although generally gray in weathered exposures, the limestones are nearly black in underground workings, and are in part shaly. They form an elongated spoon-shaped synclinal mass, a little more than a mile in length and about 300 feet in greatest thickness, that occupies the summit of a hill on the spur between Buena Vista and Cottonwood canyons. The general relations of the limestone and rhyolite are roughly shown in figure 4, which is a mere sketch with no claim to accuracy of detail or to conformity to scale. Along part of its east side the limestone is bounded by a fault plane, along which it has been dropped against the rhyolite. A smaller mass of limestone, southeast of the larger one, is similarly faulted down along its west side. This contains the Wheeler mine.

The Arizona deposit is a bed or blanket vein that conforms with the bedding of the limestone and lies approximately 25 feet above the base of this rock or the top of the rhyolite. The vein has a maximum

thickness of about 6 feet and averages about 3 feet. It is remarkably regular and persistent and appears to be practically continuous under the entire hill. The largest angle of dip observed is about 30°, and under the crest of the hill the deposit is nearly horizontal.

The old Arizona workings are at the north end of the hill, overlooking Buena Vista Canyon, and were started on a prominent outcrop of white quartz. The old stopes extend south from the surface into the hill for over 1,000 feet and have an area of about 18 acres. Practically no timber was used, and the stopes, still in excellent condition, constitute a great labyrinth of galleries between the neatly piled masses of waste that support the roof. Raymond,[a] who saw these stopes in 1871, noted the unusual basin-like form of the deposit and remarked that the conditions were more suggestive of a coal mine than of one worked for precious metals. It is a fact of some interest that deposits of this character were known and worked in Nevada at the time when our mining laws of 1866 and 1872, apparently so little applicable to them, were passed. The statement made by Shamel,[b] that "it is probable that at the date of the passage of the statute of 1872 no instance was known of a vein which assumed a horizontal or even an approximately horizontal direction," is obviously incorrect.

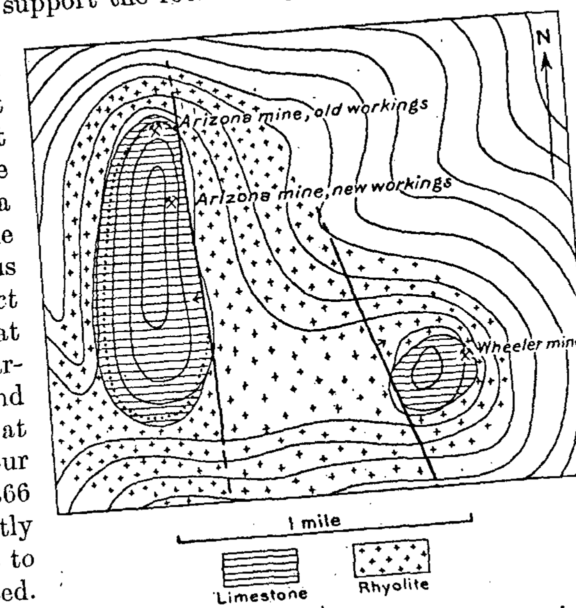

FIGURE 4.—Sketch plan showing the geologic relations of the Arizona mine.

The newer workings, which are developmental, are south of the old stopes. There are two tunnels, which connect with extensive exploratory drifts, crosscuts, and winzes or raises.

Although the vein as a whole has the form of a spoon it exhibits some structural complications. Faults, striking N. 20° to 30° W. and dipping west, step the vein down to the west. The throw is generally greater at the north, the maximum displacement observed being about 75 feet. At one place near the south end of the workings there is a slight reverse throw on one fault plane that farther north is associated with normal dislocation. The principal faulting is along the

[a] Statistics of mines and mining, Washington, 1872, p. 206.

[b] Mining, mineral, and geological law. New York, 1907, p. 233.

eastern edge of the syncline, and here the vein has been dropped against the rhyolite. In the vicinity of this fault zone both the vein and its inclosing limestones are, as a rule, disturbed. The vein is crushed, flexed, and to some extent dragged along the fault planes, some of this dragged material being good ore. The limestones are crumpled and in some places are mashed and squeezed to a structureless mass. In general, the contact of the vein with its walls is clean and without gouge. In the vicinity of the faults, however, vein and limestone have slipped past each other, and in a few parts of the mine the vein disappears and its place is taken by a seam of gouge.

The normal vein material is solid milk-white to light-gray quartz. It generally shows more or less banding parallel to its walls and in some places is divided by thin partings of limestone. There is no evidence of any important replacement, and the quartz has crystallized in open spaces produced by the separation of the limestone along one or more bedding planes. The banded structure suggests that the separation was effected by successive movements, each followed by the deposition of quartz. There is a little calcite with the quartz, but it is rare. The recognizable ore constituents are pyrite, galena, sphalerite, and tetrahedrite. As a whole the quartz is not particularly rich in sulphides, and the tendency of these is toward fine dissemination along layers parallel with the walls of the vein. Some of the gray argentiferous particles, especially where the ore has been fractured and secondarily enriched, appear to be argentite; and some of the richest ore, yielding on assay up to 1,750 ounces of silver and 0.5 ounce of gold, contains dull, greenish-black masses that are apparently mixtures consisting largely of argentite.

The richest shoots of ore have probably been mined out, but according to Mr. Carmichael[a] the average of a large number of samples from all exposed faces of the vein is about 20 ounces of silver and 0.05 ounce of gold.

At the south end of the hill, and probably on the same vein as the Arizona, is the Nevada-Union mine, which produced about $60,000. It has been long abandoned and was not visited. Southeast of the Nevada-Union is the Wheeler (formerly the Henning) mine, on a vein which, although in a block of limestone now separated by faulting and erosion from the beds containing the Arizona vein, was probably once continuous with that deposit. The Wheeler mine has always been under the same ownership as the Arizona. It was worked by flat stopes from the surface and produced probably from $100,000 to $150,000.

In Cottonwood Canyon, 3 miles south of Unionville, is the Manoa or Pfluger mine, which has been worked in a small way for many years. The principal adit is 800 feet long and connects with several hundred feet of drifts. The general country rock is rhyolite, which appears to be overlain by a rhyolitic conglomerate with a steep dip to the west. Lower down the canyon and stratigraphically below the rhyolite are volcanic (largely rhyolitic) conglomerates, grits, and shaly limestones. All these rocks were included in the Koipato formation by the Fortieth Parallel Survey geologists. The rhyolite is cut by a complex north-south basalt dike, and both rhyolite and basalt are much faulted and sheared along north-south lines. In some places this zone of disturbance is fully 400 feet wide. The general dip of the zone appears to be about 70° W., but this is not clearly shown and it is not known whether this is the same or greater than the dip of the associated beds.

[a] Oral statement.

The ore occurs irregularly as bunches and streaks in this sheared and faulted zone, especially near the basalt, and is for the most part a replacement of the crushed rhyolite by galena, sphalerite, tetrahedrite, and possibly some silver sulphantimonite, in a gangue of barite and quartz. The mine has never been an important producer.

In Jackson Canyon, between Cottonwood and Buena Vista canyons, is an antimony deposit in rhyolite that is one of the flows in the Koipato. The vein strikes N. 35° W. and dips 75° SW. It has a maximum width of about a foot, but is irregular. It is accompanied by some parallel sheeting and veining of the rhyolite. The vein consists of rather vuggy white quartz with unevenly distributed bunches of stibnite. Three tunnels have been run on the vein and some narrow stopes opened. No work was in progress in 1908 and it is not known whether any shipments have been made.

STAR CANYON AND VICINITY.

The site of the former town of Star City, whose history has already been briefly told, is 6 miles north of Unionville and about 12 miles southwest of Mill City. When visited in 1908 no mining whatever was in progress in the canyon, and although the greater part of the Sheba workings was accessible, very little could be seen of the De Soto mine, which is south of the Sheba on the opposite side of the ravine.

The rocks in the immediate vicinity of the mines are rather thin-bedded gray limestones and tuffaceous sandstones interbedded with thin flows of rhyolite and related rocks—the porphyroids of the Fortieth Parallel Survey reports. These volcanic rocks are considerably altered and are in places partly schistose, so that the original character of some of them is not altogether clear. Most of them are rhyolite or rhyolite flow breccia. Some, while containing abundant phenocrysts of alkali feldspar, have no primary quartz and may be trachytes. No glass remains in any of these rocks, and quartz, calcite, sericite, and chlorite are common as alteration products. This heterogeneous assemblage of sediments and flows is overlain, just above the mines, by the massive gray limestone of Star Peak, and is apparently underlain, below the Sheba mill, by dark slaty limestones in which the stream has excavated a more open valley than at the mines. All the rocks mentioned were placed in the Star Peak formation of the Triassic by the geologists of the Fortieth Parallel Survey, although, as noted on page 31, the abundance of volcanic material at the Sheba mine suggests the possibility of their correlation with the Koipato formation. The general strike of the beds and flows is N. 15° E. They dip 50° W.

The Sheba bonanza was close to the surface and, as the stopes and tunnels were carried into the hill, proved to be large and irregular. It consisted in part of several distinct lenticular seams of ore that followed certain bedding planes in the limestone or between the limestone and the associated grits and volcanic rocks. In many places these seams were connected by a network of veinlets across the limestone beds, and where these cross veinlets were abundant the whole mass was stoped as ore. The limestone was the rock most fractured and was the ore bearer. As a rule, fissures crossing a bed of limestone end at the plane separating this bed from grit or rhyolite.

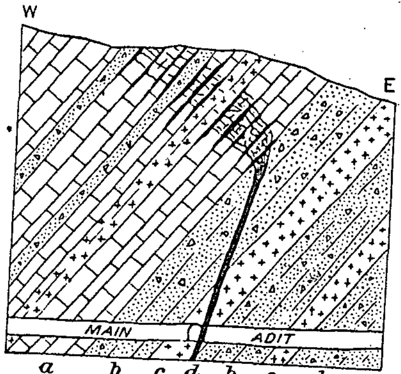

FIGURE 5.—Diagrammatic section of the Sheba ore body. *a*, Limestone; *b*, tuff; *c*, porphyry; *d*, ore.

The original pay shoots, which ramified through an area over 300 feet long from north to south and about 200 feet wide, were soon exhausted, and after vain attempts to find any deep continuation of the ore the Sheba mine was for a time abandoned. About the year 1871, however, it was ascertained that the pay shoots first stoped were connected with a well-defined and regular fissure vein. It was hoped that a new era of prosperity was at hand, but after the vein had been worked to an additional depth of rather more than 100 feet below the old stopes operations were discontinued. So far as is known, there has been no exploration of the vein below the main tunnel. The general structural relations of the deposit are diagrammatically shown in figure 5.

The main tunnel has its portal at the bottom of the canyon and runs N. 55° W. for about 800 feet through tuffs and flows to the vein, which on this level is in rhyolite. The vein strikes nearly north and dips from 65° to 75° W. It is up to 3 feet wide, consists of solid quartz with bunches of sulphides, and has been stoped on this level for about 160 feet, but apparently was here of low grade. Cutting obliquely across the layers of tuff and volcanic rock, the vein, as shown

in figure 5, maintains its regularity up to the level above the main tunnel, a distance of about 100 feet. A short way above this level it enters limestone and at once changes in character. The stopes widen to 20 to 30 feet, the vein splits, and the whole deposit becomes more irregular and, as indicated in figure 5, has a general dip across the bedding to the east.

The Sheba mine produced an antimonial silver ore consisting of white quartz carrying argentiferous jamesonite, galena, sphalerite, pyrite, and tetrahedrite. Possibly other minerals rich in silver, such as stephanite and argentite, were present in the best ore, but these were not observed in the material now visible. Jamesonite is particularly abundant. According to B. S. Burton,[a] who analyzed the minerals many years ago, the jamesonite from the Sheba mine contains over 6 per cent of silver and the tetrahedrite from the De Soto mine 14.5 per cent of silver.

During the last operation of the mine the ore was carried by an aerial tramway about half a mile down the canyon to the mill, which is equipped with rolls, Huntingtons, jigs, and concentrating tables.

The De Soto mine, which was worked in 1861 and at various times since, is immediately south of the Sheba mine and is on the same zone of mineralization. There are two tunnels. The upper one, which is very devious, extends about 600 feet into the hill, measured in a straight line. The lower one, not safely accessible at present, is about 900 feet long. The rocks are in general the same as in the Sheba mine, and the ore occurs similarly along bedding planes and in fractured limestone. Most of the lenses of ore along the bedding planes appear to be connected with one or more veins that cut the beds. The bed veins have been stoped for distances up to 100 feet from these transverse fissures, which apparently are branches of the now filled channels through which the ore-bearing solutions rose. The ore of the De Soto mine is similar in mineralogical character to that of the Sheba.

About a mile down the canyon from the Sheba mine, on the south side, is a quartz vein that cuts black shaly limestone and carries stibnite. A tunnel has been run in on the vein, but apparently the deposit was never productive.

In Bloody Canyon, a mile or two south of the Sheba mine, is another stibnite deposit, which has been worked in desultory fashion for many years and from which some shipments of good antimony ore have been made. It was not visited.

RYEPATCH MINE.

On the west slope of the Star Peak Range, 5 miles west of Unionville and 4 miles east of Ryepatch station, is the old Ryepatch mine, which after producing ore of the currently reported total value of

[a] Contributions to mineralogy: Am. Jour. Sci., 2d ser., vol. 45, 1868, pp. 36–38.

over $1,000,000 has lain idle for more than twenty years. Originally known as the Alpha or Butte mine, the property was sold about 1872 for $80,000, and took its present name at the time of that transaction.[a]

The workings, comprising several tunnels and extensive stopes, are on the north side of Panther Canyon, in thin-bedded, more or less altered limestones supposed to belong to the Star Peak formation. The metamorphism, probably due to the granitic intrusion of Rocky Canyon referred to on page 31, is not here very conspicuous, consisting chiefly of the development of one or more species of fibrous silicates, probably belonging to the amphibole group, and in some beds of a white mica in almost microscopic scales.

The structural features of the deposit, which are unusual, may be most easily understood by reference to figure 6.

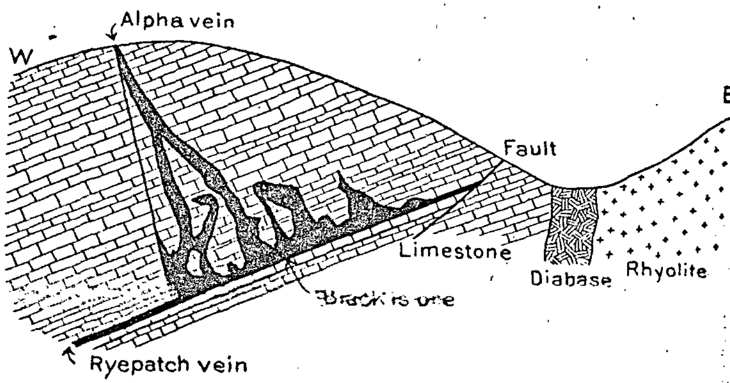

FIGURE 6.—Diagrammatic section of the Ryepatch ore body.

The Ryepatch vein, which follows the bedding of the limestone, has no recognized outcrop. Originally a shaft was sunk on a fault fissure that showed obscurely along the west side of a little lateral ravine eroded along a decomposed basic dike. (See fig. 6.) At a depth of 30 to 40 feet ore was found in a bed vein that strikes about N. 15° W. and dips 25° W. On the east this vein is cut off by the fault; on the west, at a distance of about 250 feet from the original discovery, it is joined by a fissure that strikes N. 25° E., dips 75° SE., and is known as the Alpha vein. All of the ore stoped came from the block of limestone between the two fissures. This mass is fissured in all directions and much of it is shattered to fragments. The ore, consisting of shattered limestone full of bunches and branching stringers of quartz and calcite, occurred as great irregular masses bounded in part by definite fissures but grading on most sides into country rock. The total length of the ore-bearing ground, from north to south, was about 600 feet and the total width about 250 feet.

a Raymond, R. W., Statistics of mines and mining, etc., for 1872, Washington, 1873, p. 156.

The Alpha vein itself is merely a fissure that bounds the ore on the west. It has a smooth slickensided hanging wall with practically no gouge and is not itself continuously filled with quartz. The Ryepatch vein, on the other hand, carried quartz and ore almost continuously from the point where it was first opened down to the junction with the Alpha fissure. In places this ore was narrow and had a definite hanging wall; elsewhere the ore extended from the foot wall for long distances and in very irregular fashion into the broken limestone, as roughly indicated in figure 6. The Alpha fissure, so far as known, does not extend below the Ryepatch vein. The Ryepatch vein continues westward beyond the Alpha fissure, but becomes smaller, more regular, and of much lower grade beyond the junction. A lower tunnel, some distance down the canyon from the main workings, has been run with the hope of cutting the Ryepatch vein. The vein, however, has not been identified at this depth. The tunnel follows a strong nearly north-south fissure zone, which suggests the possibility of considerable displacement of the Ryepatch vein by this or similar fissures west of the Alpha vein.

The vein material of the Ryepatch mine consists of quartz, calcite, pyrite, galena, sphalerite, tetrahedrite, and perhaps stephanite and argentite. The best ore is said to contain little or no calcite, galena, or sphalerite. No first-class ore was visible in the stopes at the time of visit.

ELDORADO CANYON.

The chief interest in Eldorado Canyon at present is derived from a deposit of cinnabar that was being prospected in 1908. The Ruby Cinnabar mine is about 6 miles southeast of Humboldt House (8 miles by road), on the northwest slope of Star Peak.

The ore occurs in a dark limestone, presumably belonging to the Star Peak Triassic, and has been opened by superficial tunneling. The beds in the vicinity dip generally west, but at the mine they are much disturbed and little was learned of their detailed structure at that place. The cinnabar is irregularly distributed through the fractured limestone, and the deposit as at present developed is a rolling, nearly horizontal mass about 80 feet long, 40 feet wide, and 6 feet thick. According to Mr. W. G. Adamson, the average tenor of the whole body is about 2 per cent of quicksilver. The cinnabar occurs as little branching veinlets, small bunches, and minute specks throughout the mass. In part it has filled fractures, but in part it has replaced crushed limestone. Some of the material through which the veinlets of cinnabar ramify is nearly black, earthy in appearance, and of noticeably high density. A lens shows that this material is crowded with minute specks of cinnabar and of pyrite or marcasite. The weight and dark color suggest also the presence of metacinnabarite, but verification of this supposition is not practicable in so fine grained a mixture of sulphides. The limestone adjacent to the ore is minutely fissured and faulted and contains many open crevices, especially under the ore body. Evidently there has been considerable removal of calcareous material by solution, and much of the fracturing associated with the deposit is probably due to the collapse of solution cavities and a settling down of the overlying rock. The workings have not exposed any vein or fissure that can be accepted as a probable main channel through which the ore constituents reached their present position.

NORTH END OF THE STAR PEAK RANGE.

North of Star Peak and Eldorado Canyon there has in the past been considerable mining activity in Humboldt, Prince Royal, Garden, Santa Clara, and other canyons. None of these old workings was visited. The Imlay (formerly the Morrison) mine, about 6 miles east of Humboldt House, is reported to be 300 feet deep with two levels. Work was in progress here in 1908 and the company was fitting up a mill near the mine.

On the crest of the range, at the head of Antelope Canyon, is the Thornton prospect, apparently in pre-Tertiary rhyolite. This was being developed in 1908, and a little rich ore was found containing free gold, associated with pyrite, sphalerite, galena, and a mineral resembling tetrahedrite, in a gangue of white quartz. Prospecting was going on also, in 1908, in Black Canyon, where the finding of some rich bunches of free gold ore in similar veins in the Triassic porphyries was causing a small influx of miners and speculators.

GENERAL FEATURES OF THE ORE DEPOSITS OF THE HUMBOLDT RANGE.

The ore deposits of the Humboldt Range, especially of the Star Peak Range, have certain common characteristics that mark their provincial unity or coherence. They occur in Triassic rocks, especially in the limestones of the Middle Triassic. Their age is not definitely known, but inasmuch as they appear to have been closely connected in origin with the folding of the Triassic and Jurassic beds it is probable that, like the gold veins of the Mother Lode belt in the Sierra Nevada, they date from early Cretaceous time. Mineralogically and structurally, however, they differ very widely from the California veins.

The ores, as a rule, are antimonial and contain much more silver than gold, with relatively little lead and zinc. Stibnite (or the similar lead sulphantimonite, jamesonite) is rather abundant, both with the silver ores and in deposits not containing notable quantities of the precious metals.

The tendency of the ores to deposit as bonanzas in certain structurally favorable places is noteworthy. It is exemplified by the bed veins of the Humboldt Queen, Arizona, and Wheeler mines and by the remarkable ore bodies of the Sheba, De Soto, and Ryepatch mines. In this connection also may be noted the close physical relation between the character of the ore body and the kind of wall rock and the fact that none of the deposits in the limestone has maintained its size and tenor when followed down into the underlying rocks. The absence of persistent veins at all comparable in richness with the masses worked within a short distance of the surface is one of the disappointing features of the region. The bonanzas apparently represent continued accumulation or enrichment, in favorable spots, of material that came in through channels insignificant in size or unsuited for the precipitation of rich ore.

PAHUTE RANGE.

GENERAL FEATURES.

The range east and south of the Humboldt Range is designated on the Fortieth Parallel Survey maps and on Spurr's[a] map as the Pahute[b] Range. Although this name is not in common use by the inhabitants of the region, it is here retained as a convenient term for the entire range, since the various names locally employed apply only to parts of the whole. Thus the northern part, east of the Humboldt Range, is commonly spoken of as the East Range; farther south it is the Table Mountain Range; and still farther south it appears on the Land Office maps as the Silver Range or the Stillwater Mountains.

From Humboldt River on the north the Pahute Range extends south for 50 miles, past Granite Peak, to the fortieth parallel. Here it bends and sweeps southwest for another 50 miles across the course of the Humboldt Range, and then again turning south continues to the vicinity of Wonder and Fairview, where it merges with other mountain groups.

The rocks of the Pahute Range are generally similar to those of the Humboldt Range. The two divisions of the Triassic are well represented, and the geologists of the Fortieth Parallel Survey have mapped some Jurassic beds along the west flank of the north end of the uplift. Exposed at several places over considerable areas, notably near Granite Peak, are masses of granite rocks, which, although referred to the Archean in the Fortieth Parallel Survey reports, are

[a] Bull. U. S. Geol. Survey No. 208, 1903, Pl. I.

[b] Or Pah Ute.

at least in part post-Triassic. It is doubtful whether any Archean rocks occur in the range. Large areas, especially southeast of Spaulding Pass, north of Sou Springs, and in the vicinity of Table Mountain, are covered by Tertiary volcanic flows and tuffs. In the course of the present reconnaissance the range was crossed at only two places, and it is consequently impossible to add anything of value to what has already been published on the general structure. The Mesozoic rocks are much folded and the axes of the folds are not related in any regular manner to the topographic axis. As Louderback[a] has shown, the form of at least a part of the range has a much closer dependence upon late Tertiary faulting than upon the post-Jurassic folding.

The mining districts are more sparse than in the Star Peak Range, and the country, especially south of Granite Peak, is less frequented and is roamed by herds of mustangs or wild horses. At the north end, about 10 miles northeast of Mill City and just south of Dun Glen Peak, is Chafey, formerly Dun Glen, in the Sierra district. Tiptop, a new camp that had not attained any importance in 1908, is just south of Chafey. South of Natchez Pass is Orofino Canyon, where some mining was done thirty to forty years ago, and Rock Hill Canyon, where are old worked-out placers. Gold Banks, not visited, is apparently situated close to the divide between Grass and Pleasant valleys, whether in the Pahute or Sonoma Range was not ascertained. It was reported that the camp, after a brief period of activity, had become very quiet in 1908.

In French Boys Canyon, north of Granite Peak, a little prospecting is going on in rocks shown on the Fortieth Parallel Survey map as Koipato Triassic. They are conspicuously metamorphosed to slates and schists, contain abundant epidote, and show very plainly the influence of the granitic intrusion to the south.

Kennedy, at the east base of the range, east of Granite Peak, is practically deserted and no work of consequence was in progress in 1908.

About 30 miles a little west of south from Kennedy, in Cottonwood Canyon near Table Mountain, are nickel and cobalt veins, and a few miles south of them some copper deposits. No work was being done at any of these in 1908.

Still farther south, on the west side of the range, is Coppereid, in the White Cloud district, where a long crosscut tunnel is being driven by the Nevada United Mining Company. The exact position of this camp, owing to the general topographic and geologic inaccuracy of the Fortieth Parallel Survey map in its vicinity, remains in doubt. It is in T. 23 N., R. 34 E., and is apparently near the place indicated

[a] Op. cit., pp. 322-327.

in Plate I. About 2½ miles north of it is Copper Kettle, where, it is reported, are some promising copper prospects, and 6 to 7 miles farther north, at the end of a low spur projecting into the valley west of Chataya Peak, is a deposit of magnetite, said to occur in greenstone, although the Fortieth Parallel Survey map, probably in error, shows Tertiary basalt at this place. According to Mr. John T. Reid, about 1,000 tons of this ore was shipped to San Francisco in 1893-4. A few miles south of Coppereid is a new prospecting camp called Shady Run.

CHAFEY AND THE SIERRA DISTRICT.

The new town of Chafey, which in the late summer of 1908 was rapidly covering the old site of Dun Glen, is 10 miles northeast of Mill City and about 20 miles southwest of Winnemucca. After the closing of the Auld Lang Syne mine many years ago a little desultory work continued near Dun Glen, especially on Munroe Hill, where the veins carry free gold near the surface. According to the excellent article by Wisker in the Mining and Scientific Press, referred to on page 14, what was known as the Hendra group of claims was bonded to H. W. Kent in 1905 for $10,000. Under his direction a vein that assayed well was cut in a short tunnel, but the discovery appears not to have been followed up. The ground was next bonded to Charles Harlowe for $30,000. He interested E. S. Chafey in the prospect, and the latter undertook to raise the necessary money to develop it. Mr. Chafey began work about June, 1908, and by September of the same year is said to have shipped enough ore to purchase the mine. When the camp was visited in September, 1908, it presented a scene of brisk activity. Buildings were going up on all sides, and freight teams and stages, almost buried in dust, were plying back and forth between the new town and Mill City.

The ravine to which the name Dun Glen appears to have been originally given runs northeast and southwest, and 2 miles south of the summit of Dun Glen Peak heads in a pass through which goes the road to Winnemucca. The length of the glen is about 4 miles, and the claims about which the present activity centers are all on the southeast side. At the northeast end of the line, just south of the pass, is the Auburn mine. About a mile southwest of it is the Auld Lang Syne mine. Both had been long idle at the time of visit. A mile southwest of the Auld Lang Syne is Chafey's mine, on the Mayflower claim, locally called the Black Hole. About half a mile southwest of this is the Golden Bell tunnel. South of the tunnel, across a small east-west ravine that opens just below the town of Chafey, is a spur known as Munroe Hill. Here are many small veins, upon which lessees were busily at work in 1908.

The rocks in the vicinity of the mines mentioned were mapped as Star Peak Triassic by the Fortieth Parallel Survey geologists, and the few hours spent in the district were not sufficient for critical revision of their stratigraphy. West of the town are dark slaty rocks supposed to be Jurassic. Similar slates underlie the town of Chafey and occupy most of the bottom of the glen, so that it is not clear from a brief examination of the district why the line separating the Jurassic and Triassic on the Fortieth Parallel Survey map should have been drawn west of Dun Glen so as to divide rocks so alike in general appearance.

As the visitor goes east from Chafey and climbs the slope to the mines, he crosses the strike of the beds and passes first over dark clay slates that strike N. 15° E. and dip 80° W. Lenses of limestone appear in the slates as the mines are approached, and along the mineralized zone itself the slate and limestone are succeeded by a belt of altered igneous rocks that are for the most part flows and flow breccias more or less interleaved with the sedimentary rocks. The width of this predominantly igneous belt was not ascertained, but was reported to be about half a mile.

The prevalent kinds of igneous rock are rather dark gray and show small dull phenocrysts of plagioclase in a fine-grained groundmass. Many are mottled and suggest squeezed flow breccias; others appear to be glassy (vitrophyric) lavas that have been rendered partially schistose. The microscope shows that the plagioclase phenocrysts are the only original minerals now recognizable. The groundmass is made up of an aggregate of quartz, calcite, sericite, kaolin, and other secondary minerals, of which the proportions vary in different flows or facies. The rocks represent vitrophyric andesite flows and flow breccias that have been folded and compressed with the slates and have developed incipient schistosity. Cutting all the rocks mentioned are dikes of normal olivine diabase (dolerite) with typical ophitic texture. In the diabase the plagioclase and the augite, which is brownish red in transmitted light, are fresh, but the olivine is more or less serpentinized. These dikes show no evidence of compression subsequent to their solidification, and were probably injected after the folding.

The Black Hole workings, which are about 1 mile east of Chafey and at over 1,000 feet greater elevation, consisted early in September, 1908, of a tunnel about 200 feet long, partly on the vein, with stopes extending about 25 feet up to the surface. Exploration was in progress also through a new inclined shaft, 60 feet deep, with short drifts.

The vein, which is of solid banded quartz up to 6 feet wide, strikes N. 50° E. and dips 45° to 50° SE. It accompanies a diabase dike and cuts obliquely across the volcanic flows and associated slates. As almost no crosscutting has been done little could be learned of the character of the wall rock. At one place the foot wall is limestone.

The vein minerals are quartz, galena, pyrite, sphalerite, and native gold, some of the gold being partly embedded in the galena. The gold seen is pale and probably contains a good deal of silver; according to Mr. Chafey the ratio of silver to gold in the ore is generally as 2 to 1, by weight. The richest ore occurred in the oxidized part of the vein, but this is very superficial. A short distance northeast of the Black Hole tunnel the vein passes into one of the andesite flows and splits up into a zone of stringers. At one place an open cut shows such a zone over 16 feet wide, with slate on the foot wall. The richest ore from the Black Hole is hauled to Mill City and shipped. The lower grades are treated (1908) in an old 3-stamp mill at Chafey.

The Golden Bell tunnel, about 600 feet long, follows a regular vein, with an average width of approximately 4 feet. It resembles the vein at the Black Hole workings and is presumably the same, although no accompanying dike was noted. The foot-wall rock was not exposed at the time of visit, but the hanging wall is altered andesitic flow breccia. Some stopes have been opened above the tunnel and evidently some ore was shipped or milled. No work, however, was in progress in 1908.

The veins of Munroe Hill strike nearly north and south and are almost vertical. They are in partly schistose andesite and andesitic flow breccia, and one of them, at least, accompanies a diabase dike. The entire zone of veins is at least 300 feet wide and appears to represent a southern extension and splitting up of the vein worked at the Black Hole. At the Bishop lease on the May Muller claim some high-grade ore was being taken in 1908 from a vein on the east side of the zone. The vein is from 1 to 2 feet wide, strikes north, and dips 80° E. It has a diabase dike along the hanging-wall side. The ore, which was being taken from an open cut near the top of the hill, was oxidized and contained free gold, with probably halogen compounds of silver. A blue-green material occurring as specks in the ore and supposed by the miners to be bromide of silver proves to be chrysocolla. At another lease, distinct from the former, although known as the Bishop & Co. lease, a tunnel was being driven on the north side of the hill to cut some ore discovered above, and at many other places on the Munroe Hill lessees were sinking shafts or beginning tunnels. The ore thus far found on the hill occurs near the surface and is probably considerably richer in gold than that below the limit of oxidation.

The Auld Lang Syne mine was worked through three tunnels down to water level, and the quantity of material on the dumps and at the site of the old mill about a mile above Chafey indicates that large and productive stopes were opened. Where the stopes come to the surface an excellent section of the vein is exposed, which is illustrated in figure 7.

The vein zone is about 100 feet wide and contains a number of nearly parallel quartz veins and stringers, separated by silicified andesite. The strike of the lode is N. 5° W. and it dips, as a whole, 65° E. On the hanging-wall side is a regular diabase dike 25 feet wide. The principal vein stoped is, as shown in figure 7, near the hanging wall of the zone. This dike, notwithstanding its proximity to the veins, is not generally altered and contains considerable olivine that has escaped serpentinization. The principal mineralogical change in the andesite, as elsewhere in this district, is the development of secondary quartz and sericite, the resulting rock outcropping and weathering much like a hard siliceous rhyolite.

The mine being quite deserted, I was able to procure no information concerning the character of the Auld Lang Syne ore. Some of the material last thrown out on the dump shows much arsenopyrite, with some pyrite arranged in depositional bands in quartz.

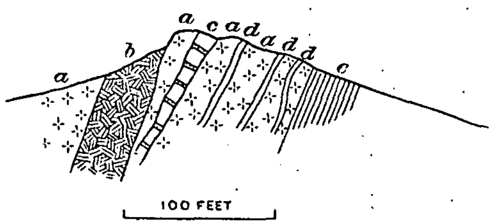

FIGURE 7.—Sketch section of the Auld Lang Syne vein zone. *a*, Silicified andesite; *b*, diabase; *c*, vein, stoped to surface; *d*, vein; *e*, slates.

Some of the veins near Chafey appear to be unusually persistent and regular. That they become lean within a moderate distance of the surface is suggested by all that can be learned of the history of the district; but one looking at the croppings of the Auld Lang Syne vein and at the work accomplished there finds it difficult to believe that the old mine will not some day be reopened, especially as its nearness to the railroad gives it and other mines in Dun Glen a great advantage over many in Humboldt County—as, for example, those at Kennedy, next to be described.

KENNEDY.

The almost deserted town of Kennedy lies at the east base of Granite (or Cinnabar) Mountain, about 30 miles by road southeast of Unionville and about 45 miles from the railroad at Mill City.

The distribution of the rocks in this vicinity is rather different from that represented on the Fortieth Parallel Survey map. The "granite" of Granite Mountain, supposed by the early geologic explorers to be Archean, is, at least locally, a diorite and is intrusive into Triassic rocks. Its outline, therefore, is undoubtedly much more irregular than they supposed. The bottom of the canyon from the

crest of the range down to Kennedy is all in the diorite, and the rock appears to extend farther north in the vicinity of Kennedy than is shown on the Fortieth Parallel Survey map. On the other hand, the hills directly southwest of Kennedy, shown as "granite," are for some miles in that direction made up of altered pre-Tertiary (probably Triassic) volcanic rocks, with perhaps some sedimentary beds.

The diorite in the vicinity of Kennedy is, as usual in such intrusive bodies, not altogether uniform, and it is possible that much of the Granite Mountain stock may be granodiorite or some quartz-bearing granular rock near that type.[a] The rock in the pass west of Kennedy appears to be fairly representative of so much of the mass as was seen at close range. This is a bright gray, medium-grained rock showing abundant hornblende and biotite in a feldspathic base whose individual crystals are not distinct to the naked eye. As seen in hand specimens, the diorite is not noticeably quartzose.

The microscope shows that the feldspars are mainly oligoclase and mottled intergrowths of oligoclase or albite with orthoclase, the whole forming a rather intricately interlocking mosaic. Green hornblende is abundant, and the larger individuals as a rule inclose and are more or less intergrown with augite that is pale green in thin section. Both these minerals are intergrown with biotite and with magnetite, apatite, and titanite. A noteworthy feature of the diorite is the generally alkalic nature of the feldspars in association with rather abundant augite, hornblende, and apatite in a rock free from quartz. It is probably near monzonite in composition, and a chemical analysis would doubtless show less lime and more alkalies than in typical diorite.

The principal mine near Kennedy is the Gold Note, credited with a production of $60,000 to $70,000, but now idle, like all others in the district, where the only active industry in 1908 was the catching of wild horses for shipment to Oregon. It is situated on the south side of the canyon, about a mile west of town, and is opened by two crosscut tunnels. The lower and main adit runs S. 33° W. and is about 700 feet long. It cuts the vein, which strikes N. 65° W. and dips 25° (or less) S., about 375 feet from the portal. The general country rock is rhyolite, which is intruded rather irregularly by sheets and dikes of basalt. The rhyolite apparently forms thi[ck] flows, and the vein and part of the basalt have followed strat[i]graphic planes in the series of rhyolitic lavas. Associated with th[e] rhyolite in some parts of the workings is a dark greenish-gray roc[k]

[a] Hague (U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 691) indeed describes the crystalline granitic ro[ck] of Granite Mountain as made up chiefly of quartz and orthoclase, with scarcely any mica or hornble[nde] (alaskite of Spurr). This suggests greater variation in the character of the rock than was evident fr[om] my own brief and limited observations.

evidently much altered, which was at first supposed to be metamorphosed limestone. The microscope shows, however, that it is an altered volcanic rock, probably andesite, and is composed chiefly of chlorite, calcite, and secondary quartz.

The basalt is a partly glassy, ordinary variety, in which some serpentinous material suggests the former presence of a small proportion of olivine. Its appearance under the microscope is that of an extrusive rock, whereas its relations underground indicate at least some intrusion. Clearly it was not intruded at any great depth.

The vein is from 1 to 3 feet wide and is composed generally of quartz and abundant pyrite. Associated with these minerals in the parts of the vein stoped are galena, sphalerite, tetrahedrite, and a little chalcopyrite. Along most of its course the vein is in rhyolite, but in some places it traverses basalt.

From the main adit drifts have been run in opposite directions. The west drift, apparently not very productive, follows the vein for about 90 feet to a zone of faulting that steps the gently inclined vein down below the level of the drift. These faults strike N. 20° W., dip west, and are normal. The first one drops the vein about 4 feet, and the second, 6 feet farther along the drift, carries the western continuation of the vein out of sight. Along the east drift the vein, at first in rhyolite, passes into basalt, becomes rather irregular, and at about 120 feet from the tunnel splits into two branches that diverge at a small angle. The north branch contains only bunches of ore. The south branch, which passes into rhyolite, has been stoped at intervals and apparently contained the principal ore bodies of the mine. At a distance of 500 feet from the adit the two branches of the vein are about 100 feet apart.

There was no one at hand in 1908 to give information about the mode of occurrence of the ore in the abandoned stopes, but it may be surmised that the pyritic parts of the vein are of low grade and that the richer ore is bunchy, difficult to mine on account of the low dip of the vein, and not amenable to treatment in ordinary mills.

The Borlasca mine lies southeast of the Gold Note and is apparently on the same vein or vein zone. The workings, which have not been productive, are all in the oxidized part of the vein and are shallow. The vein material is chiefly quartz and specular hematite, and as the unoxidized vein in the Gold Note mine is chiefly quartz and pyrite it is probable that the specularite was derived from the pyrite by weathering, although unfortunately the present workings afford no opportunity for observing the actual passage from pyrite to specularite.

In the bottom of the canyon, about half a mile above Kennedy, is the abandoned Hidden Treasure or K. and B. mine, in a rather basic facies of the diorite. An open cut exposes two veins about 18 inches

wide separated by a foot or two of decomposed diorite. The veins strike northwest and dip about 50° SW. The vein material, as indicated by the dump of the closed main tunnel, contains very abundant pyrite and some sphalerite, with a subordinate quantity of quartz and calcite.

Half a mile north of Kennedy is the Imperial mine, which is credited with a production of about $10,000. It was not visited, but is said to be in the diorite and to have yielded lead-silver ore containing some gold. Some specimens of galena seen in Kennedy were stated to have come from this mine. Attempts were made to work this ore in a 20-stamp plate-amalgamation mill with cyanide tanks, now owned by the Borlasca Company. This and the various smaller mills in the district appear to have been designed without any regard whatever to the character of the ores to be treated.

NICKEL AND COBALT DEPOSITS OF COTTONWOOD CANYON.

From Kennedy to Boyer's ranch at the mouth of Cottonwood Canyon the distance by road is about 30 miles.[a] The usual route is through Pleasant Valley past the volcanic Sou Hills and Sou Springs, the latter being about halfway in the journey. These springs consist of six or seven circular pools, 40 to 50 feet in diameter, with funnel-shaped bottoms, distributed along the crest of a calcareous tufa mound that rises from 50 to 60 feet above the alluvium of the valley. The pools differ in temperature, some being cold and some at about 85° C. A description of these springs with a good illustration (looking south toward Boyer's ranch) and some chemical analyses are given by Hague.[b] From Sou Springs south the road skirts the east face of the Stillwater Range, which is here very precipitous and is notched by narrow ravines, many of which have not cut down to the main valley, but have built up high-angle alluvial cones at their mouths. The rocks in this part of the range appear to be mainly Triassic (Star Peak) limestones cut by masses of some light-colored intrusive rock.

The topography and geology in the vicinity of Cottonwood Canyon are very inadequately represented on the Fortieth Parallel Survey map, which shows the Triassic rocks ending at the canyon, with Tertiary rhyolite south of them, all being capped to the west by basalt.

The canyon for about half a mile from its mouth is cut through dark-gray and reddish indurated clay shales, overlain by gray limestone, and this in turn by several hundred feet of light-colored thin-bedded quartzite. All three rocks are intricately intruded and contorted by tongues, dikes, and irregular masses of dioritic rock, whose

[a] Boyer post-office is on most maps of Nevada erroneously placed at the south end of the great salt playa of Osabb (Dixie) Valley, whereas it is really north of it.

[b] U. S. Geol. Expl. 40th Par., vol. 2, 1877, pp. 704-705, Pl. XX.

[...]lations to the sedimentary beds are impressively displayed in the steep bare front of the range northwest of Boyer's ranch. West of these beds, which are supposedly Triassic, the canyon for several miles is in a dioritic rock that shows considerable variation in texture and composition from place to place. Probably the most widespread variety is a medium to fine grained diorite consisting originally of plagioclase, hornblende, and perhaps augite, with considerable titanite and some apatite and magnetite. As a rule the diorite is much altered. The plagioclase is partly changed to calcite and sericite and the hornblende to epidote, calcite, chlorite, and a pale-green secondary amphibole. Other facies observed are darker and contain more hornblende, with some biotite. Still others are coarsely crystalline, are roughly foliated, and have a mottled appearance due to poikilitic development of the feldspar.

In the upper part of the canyon, in the vicinity of the nickel deposits, the diorite is intrusive into andesite and andesite breccia, much of which is so altered that its original character is scarcely recognizable. Near the diorite the andesite is silicified, carries disseminated particles and bunches of hematite with streaks of copper ore, and weathers in craggy rusty outcrops. Farther from the contact the rock is dark purplish gray and shows in places a suggestion of a tuffaceous or breccial structure and the outlines of feldspar phenocrysts. The microscope shows that the plagioclases, partly altered to sericite and calcite, are the only original minerals recognizable. The femic minerals have been changed to calcite, and particles of hematite are disseminated thickly through the groundmass.

Both the andesitic rock and the diorite are cut by dikes and by small irregular masses of a white feldspathic rock in which rutile in minute scattered crystals and grains is the only dark constituent. The grain of these dikes varies from that of an ordinary granite to that of a rather fine quartzite. The microscope shows that the plagioclase is chiefly sodic oligoclase, with a little orthoclase and probably some albite. The sharply angular spaces between the subhedral crystals of feldspar are occupied in part by calcite and in part by fine granular, microscopically radial aggregates of a mineral supposed to be quartz. The calcite is presumably secondary, as some of it has formed at the expense of the feldspars. Most of it, however, appears to have filled empty spaces by infiltration, the feldspars that inclose it preserving their original crystal outlines. The accessory minerals are rather abundant rutile with apatite and zircon. The rock is of uncommon character and will probably be briefly described in a separate publication when a chemical analysis of it is completed.

The work of the Fortieth Parallel Survey indicates that the sedimentary rocks and andesitic rocks described are probably Triassic

and that the diorite and white dikes are late Mesozoic. No additional information was obtained in the course of the present reconnaissance.

Resting upon these rocks at the head of the canyon is a thick series of nearly horizontal Tertiary volcanic rocks. Near their base is at least 300 feet of andesitic breccia with some intercalated vesicular basalt. The actual base of this series was not observed. Overlying the andesite tuffs is about 200 feet of rhyolite, covered in turn by a succession of thin volcanic flows, which, as seen from a distance, apparently include both andesite and basalt. Table Mountain is capped by these flows.

Among the many interesting geologic features of Cottonwood Canyon to which but scant attention could be given in so hasty a visit may be especially mentioned an extinct hot-spring deposit 2 or 3 miles above Boyer's ranch and about half a mile below the Nickel mine. This is a great mound of siliceous sinter surmounted by a crater-like orifice fully 200 feet above the present stream, which has cut deeply into the mound and has exposed its steep quaquaversal stratification. The deposit rests on diorite and was formed at a time when the canyon had not attained its present depth.

The Nickel mine is situated on the north side of Cottonwood Creek, from 3 to 4 miles above Boyer's ranch. It was opened about 1882, when, it is reported, a car of 26 per cent nickel ore was shipped to Camden, N. J., and was worked for eight years. It was then closed in consequence of litigation. Work was resumed in 1904 but ceased again in 1907.

The workings are on a contact between diorite and andesite or andesite breccia, the rock being too much altered for certain identification. The contact, which is here more regular than elsewhere and may be due to local faulting, strikes N. 50° E. and dips 35° NW., the diorite forming the foot wall. The ore, which is all in the andesitic rock, has been exploited by cuts, tunnels, and an inclined shaft about 200 feet deep. It occurs in narrow fissures that make various angles with the contact and are not individually persistent. Some ore has been followed for a distance of 100 feet from the contact, measured perpendicularly to that plane. The diorite in the foot wall shows fissuring and disturbance and carries stringers of quartz, but no ore.

The seams of nickel ore are rarely over 3 or 4 inches in width, and all the material seen was more or less oxidized. The original filling, of which some residual masses remain, is partly a sulpharsenide of nickel, probably gersdorffite, according to Mr. W. T. Schaller, who tested the material in the Geological Survey laboratory. It is probabl[...] chloanthite and other nickel minerals are also [...] ore has the appearance of b[...]

sulpharsenides of nickel. The residual kernels of sulpharsenide are veined and coated with a bright green hydrous nickel arsenate, probably annabergite, as determined by Mr. Schaller. This constitutes most of the ore. No quartz or other distinctive gangue mineral was noted in the veinlets. The nickel minerals are not confined to the major fissures, but have penetrated the rock in their vicinity for several inches along joints and microscopic cracks, forming a low-grade ore which the company has attempted to treat by leaching with sulphuric acid.

The Lovelock mine, about half a mile west of the Nickel mine, is reported to have shipped a total of about 500 tons of high-grade nickel-cobalt ore, but has long been idle. The workings comprise a labyrinth of superficial burrowings, by which the miners have followed or sought for the small erratic veinlets of ore, and a precarious shaft that no attempt was made to explore. This shaft is said to have been sunk to water and to be connected with exploratory drifts just above the water level. It apparently is not much more than 100 feet deep. The country rock is altered andesite like that at the Nickel mine. No diorite was seen, but it would probably be cut in deep workings.

The seams or veinlets of ore run in practically all directions and have no definite walls. The ore, all of which is partly or wholly oxidized, is more complex than that of the Nickel mine and contains copper and cobalt as well as nickel. The minerals recognized are tetrahedrite, erythrite (cobalt bloom), azurite, and green crusts that according to Mr. Schaller contain copper and nickel arsenates and sulphates and consequently may be a mixture of annabergite and brochantite.

A few miles south of Cottonwood Canyon, high on the east slope of the range, is a copper prospect which is now known as the Treasure Box, but which appears to have formerly been called the Bell Mare or Cornish mine. The ore, in the form of pyrite and chalcopyrite, is disseminated through andesitic tuff in the lower part of the Tertiary volcanic series. This impregnation extends through a belt at least a mile long and several hundred yards wide, which trends about N. 70° E. The most abundant sulphide is pyrite, the chalcopyrite occurring only here and there in bunches. The pyritization is by no means uniform and fades out indefinitely into the surrounding rock. Apparently there is no vein and no master fissure whence the mineralization has emanated.

At the east end of the deposit some oxidized copper ore has been taken from open cuts and a shaft has been sunk, apparently without the discovery of workable ore. A water-jacket furnace was erected at this place, the highest point at which the deposit outcrops, but was never used. Two tunnels, one of them about 400 feet long, have been run near the west end of the pyritic zone.

COPPEREID.

Coppereid, in the White Cloud district, on the west slope of the Stillwater Range, was the most southern locality visited in the course of the reconnaissance. The only work in progress in 1908 was by the Nevada United Mining Company, which is driving a tunnel into the south side of White Cloud Canyon at an elevation of about 1,000 feet above the valley of Carson Sink.

The lower part of the canyon is a narrow, steep gorge cut through a moderately coarse, slightly micaceous granite, intruded by many dikes of granite porphyry and by a few of diorite porphyry. Farther up the granite appears to grade into granite porphyry (although this was not established with certainty) and the porphyry is succeeded to the east by a series of limestones and calcareous shales, with a few beds of gypsum, into which it is plainly intrusive.

These sediments are overlain to the east by volcanic flows and tuffs that form the crest of the range, although on the Fortieth Parallel Survey map this is represented as being made up of the Star Peak Triassic. No fossils are known from the sedimentary rocks in White Cloud Canyon, but they are presumably Middle Triassic. They are metamorphosed by the granite porphyry intrusion, the purer limestones being marmorized and others being altered throughout by the development of garnet, epidote, fluorite, quartz, axinite, specularite, and metallic sulphides.

The workings of the Nevada United Mining Company comprise a main crosscut tunnel near the bottom of the canyon. The course of this is S. 37° E., and its length at the time of visit was 2,000 feet. On the steep hillside above the tunnel are old shallow workings that were operated about fifteen years ago for oxidized copper ore, which was reduced in a small smelter at the mouth of the canyon. Still higher, about 850 feet vertically above the main tunnel, are two tunnels known as the Twin tunnels. Both are at the same elevation, have their portals near together, and run nearly in the same general direction, so that they apparently represent an effort to explore the ground with as much labor as possible. One of these penetrates the hill for 700 feet.

About 350 feet above these tunnels is the summit of the ridge separating White Cloud Canyon from the next ravine to the south. Here is a large outcrop of specularite, which carries in places a little oxidized copper ore. There is probably from 100,000 to 200,000 tons of this material actually exposed on the hilltop and in the shallow exploratory workings that have been run into the mass. Much of it is practically pure specularite, ranging in texture from soft, greasy, rougelike varieties to coarsely foliated kinds. The copper is rather sparingly distributed through some parts of the iron ore as malachite. There are several of these masses of iron ore on the ridge. They appear to occur as pods, lenses, and irregular bodies associated with considerable fluorite and distributed through a broad mineralized zone that strikes east and west and dips about 45° N. The masses themselves strike and dip in various directions. On the west the zone, which is in limestone, ends at the intrusive contact of this rock with the granite porphyry a few hundred yards from the great hematite outcrop on the crest of the ridge.

The Twin tunnels were run under the supposition that the hematite on the ridge is the gossan of a great vein. They penetrated a little oxidized ore consisting of chrysocolla, specularite, limonite, calcite, colorless fluorite, and epidote, but disclosed nothing of value and did not cut any mass of specularite comparable with that above.

A similar expectation led to the driving of the main tunnel. The portal of this is in white to buff crystalline limestone carrying small bunches of specularite and in places much garnet and some pyrite. The beds appear to strike southeast and dip northeast, but the structure is very indistinct. At 400 feet from the portal a crosscut was driven east for 600 feet, and from this, about 200 feet in, a branch was run north to a broad zone of marmorized limestone heavily impregnated with slightly cupriferous pyrite. In places this is so abundant as to form nearly solid masses. This is probably the same zone that carries specularite near the mouth of the main tunnel and the one from which some of the oxidized copper ore was mined near the surface fifteen years ago. There is no recognizable vein; the pyrite has formed in the limestone by metasomatic replacement and is without definite boundaries. Beyond the branch the east crosscut continues for 400 feet through much broken and disturbed limestone, with many open crevices partly filled with soft, earthy limonite. The material suggests active solution by oxidizing waters, the formation of cavities, and the subsequent collapse of the cavernous rock into a mass of coarse, angular rubble.

The greater part of the main tunnel is in fine-grained dark limestone and originally calcareous shales that have been converted into dense siliceous hornstones. These are cut by many small veinlets carrying calcite, axinite, sphalerite, pyrite, and chalcopyrite. In some places they contain round or ellipsoidal concretions up to 6 inches in diameter, which when broken open show a septarian structure and a kernel of silicates, quartz, calcite, pyrite, pyrrhotite, chalcopyrite, and sphalerite. Among the silicates epidote, in short prisms and grains thickly embedded in calcite, is most abundant. It is associated with brushes of capillary crystals that have not been certainly identified but may be an amphibole—possibly tremolite.

According to a letter from Mr. John T. Reid, manager of the mine, the tunnel on January 18, 1909, was 2,750 feet in length and was making so much water from the face (1,250,000 gallons in twenty-four hours) that work had been temporarily suspended. Prior to tapping this water the tunnel passed through a number of small fissures carrying some chalcopyrite, and about 100 feet from the face, according to Mr. Reid, went through 3 feet of vein material containing chalcopyrite and pyrrhotite.

The conclusion reached from the short examination made of the main tunnel and the old workings, supplemented by a general survey of the surface, is that all the workings are in a zone of pronounced contact metamorphism, within which bunches of lean sulphides and of specular iron of irregular shape are rather erratically distributed. These show a decided tendency to form thick pods or lenses of indefinite outline, rather than distinct and persistent veins of which the positions could be calculated for depths far below their outcrops. Thus deep crosscutting involves more than the usual hazard of such a mode of exploration. While one would be rash to assert that no profitable vein will be cut in the tunnel, there is nothing on the surface or in the old workings that demonstrates the existence of any but isolated masses of ore throughout a contact zone.

The small quantity of primary ore thus far found, consisting of pyrite, pyrrhotite, and chalcopyrite, is of low grade, as is to be expected in deposits of contact-metamorphic type. The old stopes near the surface, from which ore was formerly obtained for the smelter at the mouth of the canyon, show considerable migration and concentration of oxidized copper ore, and solutions that extracted their copper from lean sulphides (or possibly from sulphides previously enriched) have deposited chrysocolla by direct replacement of crystalline limestone. The steps of this process, from narrow veinlets of chrysocolla widened by replacement, through rounded kernels of limestone inclosed in the copper silicate, to solid masses of the latter, are beautifully shown in the old stopes.

The occurrence of great masses of specularite on the top of the ridge and of large bodies of pyrite far below in the main tunnel suggested at first that the specularite was derived from pyrite by oxidation. Specularite is present, however, although not so far as known in large masses, in the lower tunnel, where it has crystallized with sulphides and garnet as a primary contact mineral. No material could be found that showed the passage of sulphides into specularite, and the evidence at this locality, while not conclusive, rather favors the view that all of the specularite is of direct contact-metamorphic origin.[a]

[a] Since this was written considerable masses of specularite intimately associated with pyrite have been cut in the tunnel 2,800 feet from the portal and about 1,000 feet below the surface. This places the contact-metamorphic origin of the specularite beyond reasonable doubt.

SONOMA RANGE.

The Gold Run district, in which the most important property is the Adelaide mine, 11 miles nearly due south of Golconda, is on the east slope of the northern part of the Sonoma Range.[a] The rocks of this part of the range are generally similar to those of the Pahute and Humboldt ranges. No attempt was made in this reconnaissance to study their lithology or structure, except at the Adelaide mine, where they have been mapped as Star Peak Triassic by the geologists of the Fortieth Parallel Survey.

The district was organized in 1866. Development apparently was slow, for in 1870 the principal shaft, the Golconda, was only 80 feet deep. South of this were the Cumberland, 50 feet deep, and the Jefferson, with still shallower workings. There were some small mills in the district, and desultory attempts were made to work the partly oxidized ores up to about 1897, when the Glasgow and Western Exploration Company acquired the mines and 15 claims along the ore-bearing zone. This company built 12 miles of narrow-gage railway from Golconda to the mine and erected a smelter and concentrating mill at the junction of its road with the Southern Pacific Railroad. This plant, consisting of two roasting furnaces and three reverberatory smelting furnaces, with the ordinary arrangement of crushing and concentrating machinery, was operated for a time on ores from Battle Mountain and from Adelaide, and some matte was shipped. The process, however, proved unsuited to the Adelaide ore and was abandoned. A few years ago the mill was remodeled and 120 concentrating tubes of the Macquisten type were installed. An interesting description of this remarkable plant has been given by W. R. Ingalls,[b] and from this the reader may obtain some idea of the ingenuity, simplicity, and effectiveness of this novel process, in which the heavy sulphides are floated off while the gangue minerals sink. Some improvements in the first installation were in contemplation in 1908, and the mill was in use by Mr. Macquisten solely for experimental purpose. Its total capacity was given as 120 tons in twenty-four hours. It produced when in full operation a 20 per cent concentrate from 2.7 per cent copper ore, leaving about 0.2 per cent in the tailings. The weakest point in the process appears to be in the relatively low recovery from the slimes.

The main shaft of the Adelaide mine, 300 feet deep, is situated on the south side of Gold Run Creek, close to the site of the old settlement of Cumberland. The general country rock is dark calcareous slate, within which is a layer or series of beds of limestone from 50 to 75 feet in total thickness. This bed strikes north and dips 65° E.

[a] The Havallah Range of the Fortieth Parallel Survey reports.
[b] Concentration upside down: Eng. and Min. Jour., vol. 84, 1907, pp. 765-770.

This limestone layer carries the ore, which in some places occupies the full width from one slate wall to the other, although as a rule the zone contains horses of altered limestone that is nearly free from sulphides. The ore body is undoubtedly large and has been extensively stoped above the 100-foot level for 400 feet without any indication of a diminution in size. Below this level, which is approximately at the bottom of the zone of partial oxidation, exploratory drifts have been run at vertical intervals of about 50 feet, revealing abundant ore. The bottom level was under water at the time of visit.

The ore is a metasomatic replacement of the limestone and consists of pyrrhotite, chalcopyrite, sphalerite, and a little galena, in a gangue of garnet, vesuvianite, diopside, calcite, orthoclase, and a very little quartz. Common pyrite is probably not altogether absent, although it does not appear in the specimens of ore collected. The presence of orthoclase is uncommon in this mineralogic association, but adularia has been noted by Spurr and Garrey [a] in the altered limestones of the Velardeña contact zone. At Adelaide the orthoclase is poikilitic and contains inclusions of vesuvianite, garnet, diopside, and quartz. The ore is definitely bounded only where it is in contact with the slates. Elsewhere it merges gradually and irregularly into limestone containing silicates but very little of the sulphide constituents. A banding of the limestone, due to alternations of silicate and calcite layers, is common, particularly near the ore, and the bands in places are contorted and crumpled. As a whole the ore is of low grade, averaging about 3 per cent of copper; but the quantity available appears to be large, and the difficulties in the way of its successful concentration and treatment will probably soon be overcome.

The present workings do not afford much evidence of secondary enrichment. The old stopes between the 100-foot level and the surface were in mixed sulphide and oxidized ore, but whether chalcocite was present in quantity is not known.

About 600 feet north of the main shaft, on the opposite side of the little creek, is a tunnel that runs north in the ore zone for 2,000 feet. For a distance of 500 to 600 feet from the portal the tunnel is in ore. Beyond this the limestone zone is generally lean or barren, although there are a few bunches of ore near the face and some stopes above the tunnel were formerly worked from a now abandoned shaft on the hilltop.

A notable feature of the Adelaide ore bodies, in view of the fact that the nearest area of eruptive rock (mapped as granite on the Fortieth Parallel Survey map) is fully a mile east of the mine, is their close correspondence to ores of typical contact-metamorphic deposits. The granitic rock was not examined in 1908. For at least a quarter of a mile east of the mine the rocks are dark clay slates alternating

[a] Ore deposits of the Velardeña district, Mexico: Econ. Geology, vol. 3, 1908, p. 708.

with thin-bedded limestones. All are much crumpled but maintain a generally east dip and are on the whole much less metamorphosed than the limestone beds in which the ore occurs. It is probable that an intrusive mass underlies the sedimentary rocks at the Adelaide mine, and that the hot mineralizing solutions rose along what is now the ore zone, in consequence of favorable fissuring in this particular belt of limestone.

West of the mine the slopes, seen from a distance, show many outcrops suggestive of rhyolitic porphyries, which accord in general with the mapping of the higher part of the range by the geologists of the Fortieth Parallel Survey as Koipato Triassic. Within these a number of prospectors are developing veins that carry some gold and silver. None of these prospects was visited.

MINERALOGY OF THE ORE DEPOSITS.

Introductory statement.—For convenience of reference the minerals noted in the ores or closely associated with them are here given in alphabetic order, with brief notes on their occurrence. The list is obviously not an exhaustive one for the region, which contains many deposits not visited.

Amphibole.—A fibrous mineral, not certainly identified, but closely resembling tremolite, occurs with epidote, vesuvianite, garnet, and sulphides in the metamorphosed calcareous rocks at Coppereid. A similar fibrous mineral was noted in some of the altered limestone at the Ryepatch mine.

Annabergite.—A bright-green, hydrous nickel arsenate, probably annabergite, is an important constituent of the ore of the Nickel mine in Cottonwood Canyon, west of Boyer post-office.

Argentite.—Sulphide of silver has been found in shallow workings in rhyolite at Rosebud, associated with kaolinite, limonite, and jarosite. Presumably it was present also in some of the rich silver ores mined in former days near the surface in the Humboldt Range. A specimen of ore seen in Unionville and said to have come from the Arizona mine apparently contains argentite.

Arsenopyrite.—The sulpharsenide of iron was noted only in material on the dump of the Auld Lang Syne mine, near Chafey, associated with pyrite and quartz.

Axinite.—Axinite, a complex borosilicate of calcium, aluminum, and other bases, occurs in the altered calcareous shales of the Coppereid contact zone.

Azurite.—The blue hydrous copper carbonate is nowhere abundant in the region examined, but is present in small quantity in the Red Butte copper district and at the Lovelock cobalt-nickel mine, in Cottonwood Canyon.

Barite.—Sulphate of barium was noted as a gangue mineral in ore from a prospect near Fitting; with galena, sphalerite, tetrahedrite, and quartz in the Manoa or Pfluger mine, near Unionville; and in some of the copper prospects at Red Butte.

Bornite.—Minute specks of a mineral resembling bornite were noted with chalcopyrite in quartz at the Mazuma Hills mine, in the Seven Troughs district. Not enough of the material was obtained, however, for a satisfactory determination.

Brochantite.—Brochantite, a green basic sulphate of copper resembling malachite, probably occurs in the cobalt-nickel ore of the Lovelock mine.

Calcite.—Calcite is sparingly present with quartz in the ores of the Humboldt Queen and Arizona mines, in the Humboldt Range, in some of the veins near Kennedy, and in the deposits of contact-metamorphic type at Coppereid and Adelaide.

Cerargyrite.—Cerargyrite, or horn silver, is generally an inconspicuous mineral and probably occurred in many of the rich silver deposits formerly worked in the Humboldt Range.

Chalcocite.—Copper glance, cuprous sulphide, was noted only at Red Butte, in a vein in gabbro. It is probably present also in the upper parts of the ore bodies at Adelaide.

Chalcopyrite.—Copper pyrite is an important constituent of the Adelaide ore, associated with garnet, vesuvianite, epidote, diopside, calcite, quartz, orthoclase, pyrrhotite, sphalerite, galena, and pyrite. It is present also in the cobalt-nickel ore of the Lovelock mine; in the disseminated pyritic deposits of the Treasure Box mine, southwest of Boyer's ranch; in some of the veins near Kennedy; and sparingly in the Mazuma Hills mine, at Seven Troughs. Close search would probably show it to be present in small quantities also in most of the mines of the Humboldt Range.

Chloanthite.—A mineral of the smaltite-chloanthite group is perhaps present with gersdorffite at the Nickel mine, in Cottonwood Canyon, but it has not been definitely identified.

Chrysocolla.—The hydrous silicate of copper occurs in the oxidized zone of the Copperoid contact deposits, where to some extent it has metasomatically replaced limestone. It is sparingly present at Red Butte and is found in minute specks in some of the oxidized ore of Munroe Hill in the Chafey district.

Cinnabar.—The red sulphide of mercury occurs in fractured limestone in Eldorado Canyon, in the Humboldt Range; in a vein in limestone and in kaolinized rhyolite in American Canyon, in the Pahute Range; and at an unvisited prospect on the edge of the Black Rock Desert, a few miles south of Red Butte. It has also been found in the gold-bearing gravels of American Canyon.

Copper.—Native copper was noted only near Red Butte, where it is disseminated through aplitic dikes that cut gabbro.

Covellite.—The deep blue cupric sulphide occurs sparingly as a product of weathering in the superficially opened copper prospects of Red Butte.

Cuprite.—Earthy cuprite occurs with covellite, chrysocolla, and iron oxides at Red Butte.

Diopside.—Monoclinic calcium-magnesium pyroxene occurs with garnet, vesuvianite, orthoclase, and sulphides in the ore of the Adelaide mine.

Epidote.—Epidote, a basic orthosilicate of calcium, iron, and aluminum, is fairly abundant in the contact zone at Coppereid, associated with garnet, specularite, axinite, and sulphides.

Erythrite.—Cobalt bloom, a hydrous cobalt arsenate, is an important constituent of the ore of the Lovelock mine in Cottonwood Canyon. It is associated with tetrahedrite, azurite, and arsenates and sulphates of nickel and copper (probably annabergite and brochantite).

Fluorite.—Fluorspar is fairly abundant in the contact zone at Coppereid and is especially associated with specularite.

Galena.—Galena is widely distributed in the Humboldt region, and is found in the ores of nearly all of the districts visited. None was seen, however, in the Seven Troughs district. Specimens from the Imperial mine near Kennedy showed enough galena to constitute a lead ore, but as a rule the mineral is disseminated rather sparingly through quartz with sphalerite, pyrite, and tetrahedrite. At Chafey free gold and galena are directly associated. In Star Canyon galena and jamesonite occur together.

Garnet.—Brown garnet is abundant at both Coppereid and Adelaide, where it occurs with other silicates and with sulphides in altered limestone.

Gersdorffite.—The principal unoxidized constituent of the ore of the Nickel mine, in Cottonwood Canyon, is, according to Mr. W. T. Schaller, probably gersdorffite, a sulpharsenide of nickel. It is associated with a green alteration product, which he has determined as annabergite.

Gold.—Native gold occurs in visible masses, some of them of unusual size, in the quartz veins of the Seven Troughs district. It is also found associated with quartz and galena in the Chafey district and in various prospects in the Humboldt Range near Star Peak. Specimens of free gold have been found also in rhyolite just south of Golconda, but not in such form or quantity as to induce deep mining.

The principal placer localities of the region are American Canyon and Spring Valley (Fitting), on the east side of the Star Peak Range, and Rock Hill Canyon, in the East Range. Several other canyons, especially in the northern part of the Star Peak division of the Humboldt Range, also yielded some placer gold.

Hematite.—Large masses of specularite occur in the contact-metamorphic zone at Coppereid, and the same mineral is abundant in the superficial workings of the Borlasca mine, near Kennedy. In the latter place the specularite is possibly gossan material derived from the oxidation of pyrite. Some cryptocrystalline siliceous hematite occurs in the Red Butte district, associated with the copper ores. The material, which is in part jasperoid, appears to have been formed by alteration of parts of the aplitic dikes.

Jamesonite.—Jamesonite, a sulphantimonite of lead with considerable resemblance to stibnite, is an abundant constituent of the ore of the Sheba and De Soto mines, in Star Canyon. It is associated with galena, sphalerite, tetrahedrite, and pyrite in quartz. Both the jamesonite and the tetrahedrite, as shown by Burton,[a] are silver bearing.

Jarosite.—Jarosite, a hydrous sulphate of alkalies and iron analogous in its formula with alunite, was identified microscopically as minute yellow crystals associated with kaolinite and limonite at the Brown Palace mine, near Rosebud.

Magnetite.—Masses of iron ore, chiefly magnetite, occur about 20 miles southeast of Lovelock, at the northwest base of the Pahute Range. The deposits, said to be in "greenstone," were not visited.

Malachite.—The green hydrous carbonate of copper is present in small quantities at Red Butte, Coppereid, Adelaide, Cottonwood Canyon (Stillwater Range), and probably at other localities where ores containing copper minerals have undergone oxidation.

Orthoclase.—The potassium feldspar orthoclase occurs with garnet, vesuvianite, diopside, calcite, and sulphides in the ore of the Adelaide mine. The mineral is xenomorphic and poikilitic, containing inclusions of the minerals associated with it.

Proustite.—Ruby silver has been reported from the Seven Troughs district. None was seen in 1908.

Pyrrhotite.—Magnetic pyrite is an abundant constituent of the ore of the Adelaide mine and occurs also in the contact zone at Coppereid.

Silver.—Native silver is said to have been found in Wildhorse Canyon, in the Seven Troughs district.

Sphalerite.—Zinc blende is a very widely distributed mineral in the Humboldt region and occurs in nearly all of the districts visited. It was not observed, however, at Seven Troughs. It is not as a rule abundant at any one place, but, like galena, is disseminated rather sparingly through the various ores.

[a] Contributions to mineralogy: Am. Jour. Sci., 2d ser., vol. 45, 1868, pp. 36–38.

Stibnite.—The widespread distribution of stibnite, or antimony glance, is characteristic of the region covered by this reconnaissance. Deposits of stibnite have been worked in the Trinity or Antelope Range, southeast of Red Butte; in the Humboldt Range, southeast of Lovelock; in Star Canyon; in Bloody Canyon, 2 miles south of Star Canyon; in Jackson Canyon, about a mile south of Unionville; and in the Bernice district, about 16 miles south of Boyer's ranch, where there was at one time considerable activity. The Bernice district is south of the area studied in 1908. Stibnite occurs also associated with some of the gold ores at Seven Troughs, and is undoubtedly present at many localities not examined in the course of this preliminary investigation. The mineral occurs generally in fissure veins with quartz, although at Seven Troughs it forms bunches in soft, crushed rock or gouge.

Sulphur.—Native sulphur is extensively mined at the Rabbit Hole sulphur mine, about 5 miles northwest of Rosebud.

Tetrahedrite.—Gray copper, or tetrahedrite, like sphalerite and galena, occurs in most of the silver-gold deposits of the Humboldt and Pahute ranges. It is nowhere very abundant nor in large masses, but is disseminated in specks or small bunches through the predominant quartz gangue. As a rule it is argentiferous (freibergite) and its presence indicates an ore rich in silver. The tetrahedrite of the De Soto mine, according to Burton,[a] contains 14.5 per cent of silver.

The mineral was noted in the ores of the Humboldt Queen mine; of the Arizona, Wheeler, and Manoa mines, near Unionville; of the Sheba and De Soto mines, in Star Canyon; of the Ryepatch mine; and of the Gold Note mine, near Kennedy. It also occurs with cobalt minerals at the Lovelock mine.

Tourmaline.—Tourmaline was not observed in close association with ores, but occurs as an abundant microscopic constituent of altered limestone or calcareous shale near the Humboldt Queen mine.

Vesuvianite.—The characteristic contact-metamorphic mineral vesuvianite, a basic calcium-aluminum silicate of uncertain formula, occurs abundantly with garnet, diopside, calcite, quartz, orthoclase, and sulphides at the Adelaide mine. It was identified by its optical properties as seen under the microscope.

TYPES OF DEPOSITS REPRESENTED IN THE REGION.

Basis of classification.—The ore deposits of a given region may be classified in many different ways, as, for example, (1) by geologic age, (2) by form, (3) by supposed origin, (4) by mineralogic character, or (5) by essential metallic contents. In the present paper an attempt will be made to group the deposits primarily with reference to the closely related fourth and fifth bases of comparison. The grouping thus effected will to some extent coincide with classifications dependent upon genetic or morphologic features.

[a] Loc. cit.

Antimonial silver deposits.—A large proportion of the deposits of southern Humboldt County consist essentially of silver ores carrying varying minor quantities of gold. These ores are prevailingly antimonial, the silver being combined chiefly in tetrahedrite or jamesonite. They generally contain in addition a little galena (probably argentiferous) and sphalerite, with of course some pyrite. The gangue is quartz, and as a rule the sulphides are subordinate to the gangue and are rather finely disseminated through it. Argentite and other rich silver-bearing minerals may occur in the upper parts of some of these deposits.

To this class belong the deposits of the Sheba and De Soto mines, in Star Canyon; of the Arizona, Wheeler, and other mines near Unionville; of the Humboldt Queen and Ryepatch mines; of the principal mines at Kennedy and Fitting; and of a number of unvisited mines and prospects in the Humboldt Range. Possibly the deposits of the Rosebud district belong in this group, but too little ore has yet been found there to furnish a safe basis for comparison.

With the exception of the doubtful ores at Rosebud, all of these deposits are in Triassic rocks and most of them are in the Star Peak formation. Beyond the fact that the ores are post-Triassic their age is unknown, but it is thought probable that they are pre-Tertiary and were deposited during or after the post-Jurassic intrusions and folding that affected the whole Great Basin region and the Sierra Nevada.

The antimonial silver ores generally fill fissures, but they show much variety in form. Some deposits, as that of the Bonanza King mine at Fitting, are comparatively simple, nearly vertical veins. Some, while generally of simple tabular form, have a low angle of dip, as in the Gold Note mine, at Kennedy, or are nearly horizontal, as at the Arizona mine, near Unionville. Others are of irregular shape and are related in special ways to fissuring and bedding, as in Star Canyon and at the Ryepatch mine. Still others, such as the Humboldt Queen deposits, are sharply folded bed veins.

None of these deposits has been worked to great depth, and the rich ores appear to form bonanzas within short distances from the surface. As a rule, the deeper workings show a decrease both in the size and tenor of the deposits. At present there is no production from any mine in ore of this type, although many of them were extensively and profitably worked in the sixties.

Gold-silver deposits.—The deposits that owe their value chiefly to gold are those at Seven Troughs and at Chafey. There are marked differences, however, between the ores of the two districts. Those at

Seven Troughs are in Tertiary volcanic rocks; those at Chafey are in Mesozoic volcanic and sedimentary rocks, probably Triassic. At Seven Troughs the gold is coarse, occurs in lodes made up of many small irregular quartz veinlets, and is accompanied by comparatively little pyrite, with as a rule no other sulphides. Stibnite, it is true, occurs in some of the mines, but not, according to my observation, as a constituent of actual ore. At Chafey the native gold is in smaller particles and occurs in well-defined solid veins in which the quartz carries considerable galena, less sphalerite, and comparatively little pyrite. Whether the veins of the Auld Lang Syne and other abandoned mines exhibit the same character is not known, although arsenopyrite appears to have been the principal sulphide in the lower levels of the Auld Lang Syne. Neither at Seven Troughs nor at Chafey were the accessible workings deep enough in 1908 for a thoroughly satisfactory comparison of the two kinds of deposits.

Gold prospects, of which the ores resemble the Chafey ore, in that the gold is associated with galena and sphalerite in quartz veins traversing Triassic rocks, have been opened at various places in the region, particularly in the vicinity of Star Peak.

Copper deposits.—Like the gold deposits, the copper deposits of the region fall into two classes. One of these is exemplified by the deposits southwest of Boyer's ranch, in Tertiary andesite, and by those at Red Butte, which are in igneous rocks doubtfully regarded as of Tertiary age. The deposits near Boyer's ranch are diffuse pyritic disseminations. Nothing is known of the Red Butte deposits beyond what may be seen from very shallow workings in oxidized material; the greater part of the copper appears to be disseminated through altered aplitic dikes in gabbro, and the native metal may be expected to give place in depth to some sulphide, perhaps to chalcopyrite.

The deposits at Coppereid and Adelaide, on the other hand, are in calcareous sedimentary rocks, probably belonging to the Triassic. They have the mineralogical characteristics of contact-metamorphic deposits, although at Coppereid only is there visible relation between the metamorphism and a mass of intrusive rock that effected the alteration. Garnet, chalcopyrite, pyrrhotite, sphalerite, and pyrite are common to both localities, although no sulphide ore bodies have yet been opened at Coppereid. Axinite, fluorite, epidote, and specularite occur in the contact zone at Coppereid, but were not noted at Adelaide. At the latter place, on the other hand, the altered limestone contains vesuvianite, diopside, and orthoclase. Doubtless a more thorough study would increase the lists of silicate minerals present at each locality. The deposit at Adelaide, like those at Yerington,[a] shows that ore bodies of essentially contact-metamorphic type are not necessarily in direct contact with igneous rocks near the surface.

[a] Ransome, F. L., The Yerington copper district, Nevada: Bull. U. S. Geol. Survey No. 380, 1909, pp. 99-119.

Antimony and quicksilver deposits.—The general character and distribution of the deposits of stibnite and cinnabar have been briefly outlined in the preceding section on the mineralogy of the ore deposits. The occurrence of both kinds of ores at a number of widely separated localities is one of the noteworthy features of this part of Nevada, and indicates that the ore deposition, in spite of its varied local manifestations, has had some ultimate dependence upon conditions regional in their prevalence. In other words, the ores show a general provincial relationship.

The antimony and quicksilver deposits, with the exception of the stibnite at Seven Troughs, are all, so far as is known, in Triassic or Jurassic rocks and are supposedly of the same age as the antimonial silver-gold ores. No facts are known, however, that absolutely rule out a Tertiary age for some of these deposits.

Nickel and cobalt deposits.—The nickel and cobalt deposits in Cottonwood Canyon consist of sulpharsenides of nickel (gersdorffite in part), tetrahedrite, and some compound of cobalt with sulphur, arsenic, or antimony, with the various oxidation products of these minerals. The ores fill small fissures in much-altered andesite or andesite breccia cut by diorite and may be genetically related to the intrusion of the latter rock. The age of the diorite is probably late Mesozoic. The age of the nickel and cobalt ores is not definitely determinable. If their deposition followed closely the intrusion of the diorite they are probably pre-Tertiary. On the other hand, the occurrence of copper both with the nickel and cobalt ores and in Tertiary andesite at the Treasure Box mine, a few miles south of Cottonwood Canyon, suggests that the nickel and cobalt deposits may be Tertiary.

CONCLUSION.

The southern portion of Humboldt County is part of a metallogenetic province characterized chiefly by the prevalence of antimonial ores of silver with numerous and widely scattered deposits of stibnite and cinnabar. There are in addition some deposits of gold-silver, copper, and nickel-cobalt ores. Ore deposition probably began immediately after the intrusion of the Triassic and Jurassic sediments in late Mesozoic time by a magma of generally granodioritic composition, comparable with that which invaded the rocks of the Sierra Nevada at the same period, and continued into the Tertiary. The known Tertiary deposits are essentially gold-silver ores and copper ores, but it is possible that some of the other types are also Tertiary.

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Evaporite-Carbonate Rocks of the Jurassic Lovelock Formation, West Humboldt Range, Nevada

ABSTRACT

The Lovelock Formation is an assembly of late Early Jurassic or Middle Jurassic carbonate rocks and gypsum that constitute the youngest preserved sediments and, probably, the last marine deposits in successions of Jurassic rocks in the Carson Sink region of western Nevada. The formation records a set of transitional environments between open marine basinal conditions and an emergent tectonically active terrain. The current extent of the formation is probably a small fraction of its original distribution in the Carson region and, perhaps, in areas of Nevada farther west.

The Lovelock Formation occurs only in a pair of nappes in the nappe pile of the northern West Humboldt Range. Geometric relations between intranappe and internappe folds suggest that nappe emplacement and folding were coupled deformations in major Middle Jurassic tectonism. Sites of deposition of the Lovelock Formation were probably not more than a few kilometers east or west of current exposures of the formation.

The formation is comprised of three members in a maximum thickness of about 200 m. The lowest is a micrite which underwent emergence and fresh-water diagenesis before deposition of fragmental limestones of the middle member. Conglomerate of the middle member consists exclusively of intraclastic micrite pebbles from the lower member. Finer grained sedimentary breccia above the conglomerate is an accumulation of intraclasts and allochthonous particles from a variety of subenvironments on a carbonate bank. The upper member comprises gypsum and calcarenite, deposited at least in part in standing water of a barred basin. The sequence of motions of the sediment surface relative to sea level recorded in the deposits of the Lovelock Formation is conceivably due to eustatic variations, but the general temporal proximity of deposition of the formation to major tectonism suggests that such motions were probably tectonic.

Postdepositional hydrothermal recrystallization occurs sporadically in carbonate rocks of the Lovelock Formation. Such metamorphism was perhaps synchronous with local generation of solution breccias in the upper member and local calcitization of sulfate.

INTRODUCTION

Gypsum and carbonate rocks, here named the Lovelock Formation, constitute the apparently youngest marine deposits in early Mesozoic sedimentary successions exposed in the West Humboldt Range, Nevada (Fig. 1). Outcrops of the formation are limited to a pair of nappes in an area of only a few square kilometers. It is likely, however, that the preserved deposits of the Lovelock Formation are a vestige of a once more extensive lithic unit in the Carson Sink region and perhaps, in areas farther west. The rocks of the formation record paleoenvironments that were transitional from open marine basinal conditions in Lower Jurassic time to an apparently emergent, tectonically active terrain in upper Lower Jurassic or Middle Jurassic time. Thus, the Lovelock Formation and the probably correlative Boyer Ranch Formation (Speed and Jones, 1969) east of the Carson Sink were the last marine sediments of the Carson region and were deposited at the onset of or during major tectonism. This paper examines the stratigraphy and lithology of the Lovelock Formation with a view toward interpretation of its depositional and tectonic history.

Aside from its paleoenvironmental significance, the Lovelock Formation provides a key to certain lithic and structural problems of the Carson Sink region. The nappes that contain the Lovelock Formation in the northern West Humboldt Range (Gypsum Mtn., Fig. 1) occur in a pile of nappes of lower Mesozoic rocks. Nappe piles of essentially similar rocks exist farther south in the West Humboldt Range and at places in the Stillwater Range to the east across the Carson Sink. A major exception to the uniformity of the lithic assemblies of such nappe piles is that the Lovelock Formation is apparently absent from nappes of the Carson region (other than the nappe pair at Gypsum Mountain). The highly restricted occurrence of the formation has been puzzling, considering that associated early Mesozoic pelites are so widely distributed.

Nappe piles of the Carson region, however, contain a number of laterally extensive tabular bodies of carbonate breccia and marble which are apparently much like the rauhwackes[1] of the alpine chains (Leine, 1971). In the Carson region, the marble in such bodies is believed to have originated by calcitization of gypsum and the breccia by compaction and collapse of carbonate residua during aqueous dissolution of the remaining sulfate (Speed, 1974). The extent of the carbonate bodies in the Carson region indicates that precursor gypsum was widespread. There is no recognized stratigraphic interval of sulfate rocks in the Carson region other than that in the Lovelock Formation, and by correlation, it follows that the Lovelock Formation was similarly widespread. Support for the correlation is derived from the existence of small bodies of marble and breccia in the gypsum unit of the Lovelock Formation. Study of the Lovelock Formation thus provides the "initial conditions" for calcitization and brecciation in the production of the Carson rauhwackes. Description of the rauhwackes and the transforming processes is presented elsewhere (Speed, 1974; Speed and Clayton, 1974).

Earlier mention of rocks of the Lovelock Formation was made by Louderback (1904) and by Stone and others (1920), but they did not provide a correct stratigraphy because of unresolved structural complications. Wallace and Silberling (1962) give a reconnaissance cross section which includes rocks of the Lovelock Formation approximately along the same line as section AA′ of Figure 2 of this paper.

LITHIC UNITS OF THE NORTHERN WEST HUMBOLDT RANGE

The Lovelock Formation crops out entirely in the northern West Humboldt Range, Nevada, about 8 km northeast of Lovelock. It occurs in a relatively complete but structurally complicated succession of Lower Jurassic and Upper Triassic sedimentary rocks, together with minor breccia and igneous rock. The lithic units

[1] Rauhwacke: name applied in Europe, especially in the Alps, to laterally extensive tabular bodies of porous carbonate breccia or rocks in which carbonate breccia is the major constituent (Leine, 1971). In the alpine chains, rauhwackes are frequently nappe soles. I import the name as a convenient and general lithic descriptor. There is no genetic connotation involved.

Geological Society of America Bulletin, v. 85, p. 105–118, 6 figs., January 1974

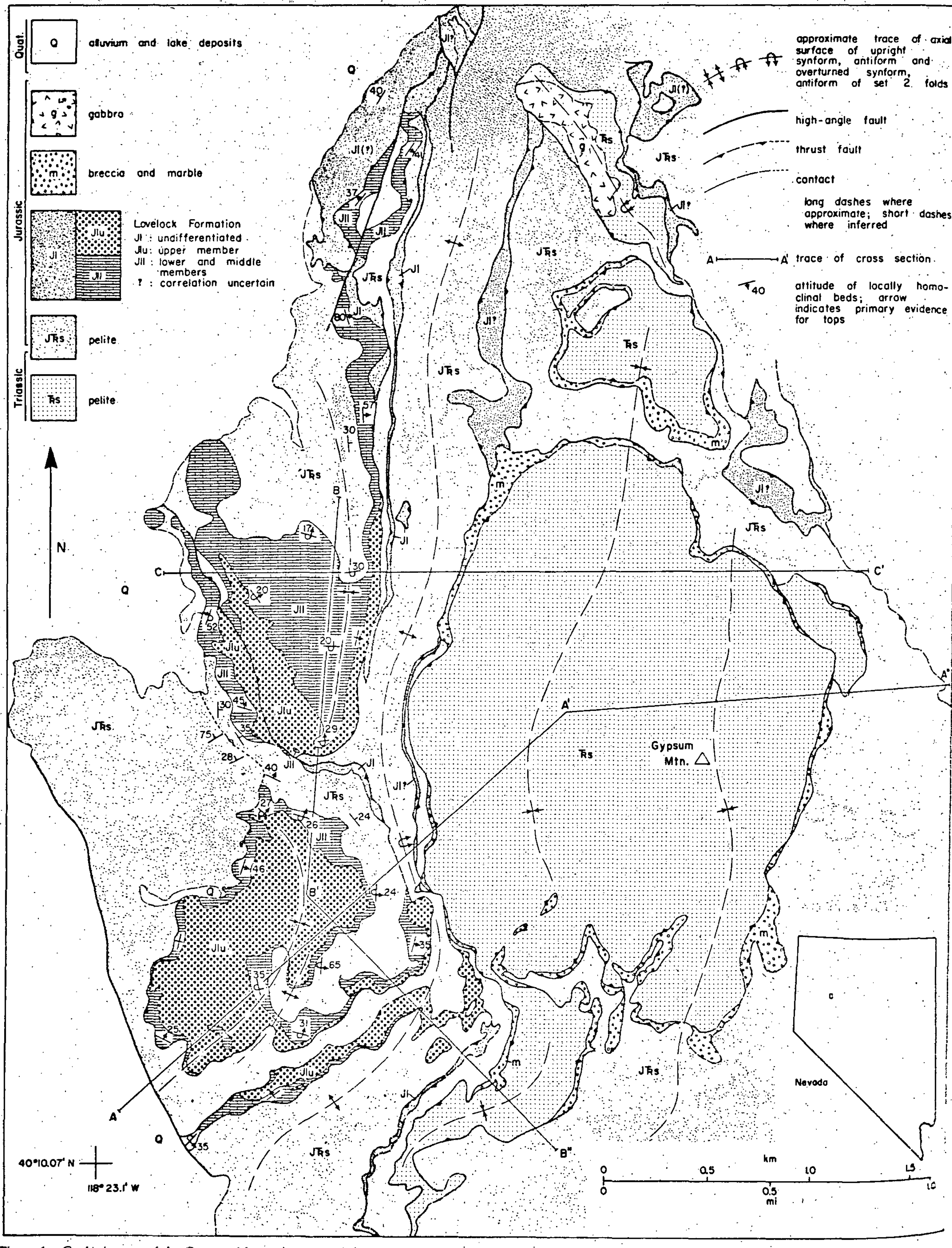

Figure 1. Geologic map of the Gypsum Mountain area, northern West Humboldt Range, Nevada, showing outcrop extent of Lovelock Formation and probable correlatives (Jl?) at the same structural level. Cross sections in Figure 2. Topography from U.S. Geological Survey Lovelock (1:62,500) quadrangle; elevations in feet.

associated with the Lovelock Formation are briefly described below, and their distributions are shown in Figure 1.

Pelite[2], Principally Lower Jurassic (J₹s)

The volumetrically predominant rocks of the area of Figure 1 are light colored, laminated to thin-bedded mudstone and siltstone. They contain minor thin to medium beds of calcareous sandstone and thin-bedded to massive sandy, silty, and stromatolitic dark limestone. Fossils obtained in the unit indicate Early Jurassic Hettangian, Sinemurian, and Toarcian ages. The youngest fossils (early Toarcian) are *Harpoceras* sp., identified by N. J. Silberling, which have been collected at several localities in the area of Figure 1 by Silberling and by me. The Lower Jurassic pelites exhibit no recognized stratigraphic succession of lithic variations. Thus, in the area of Figure 1 where probably all the rocks are in thrust nappes, allochthonous bodies of pelite cannot be assigned to a particular stratigraphic position in the succession by lithology. As a unit, however, the Lower Jurassic pelites are lithologically distinct from most Triassic pelitic rocks which constitute the other widespread unit of pre-Tertiary layered rocks of the Carson region.

Sulima (1970) studied an apparently continuous section of Lower Jurassic pelite in Coal Canyon 2 km north of the area shown on Figure 1. He found at least 1,000 m of Hettangian rocks which are conformable above Triassic (Norian) pelite. The Triassic rocks are largely dark slate which contrast strongly with the Jurassic pelite. An unfossiliferous interval about 100 m thick occurs above the Triassic slate in rocks lithologically similar to the Jurassic pelite. The systemic boundary could thus occur within the light-colored, more calcareous higher pelite succession; such rocks are here called J₹s, though most of them are Lower Jurassic. The Lovelock Formation lies conformably above pelite of this unit.

Triassic Pelite (₹s)

Slaty light- to dark-green mudstone and siltstone, minor micaceous sandstones, and dark limestone make up the Triassic pelite unit. Abundant *Monotis subcircularis* and other fossils indicate the unit is Norian (late Late Triassic). Triassic pelite in the area shown on Figure 1 occurs only in the youngest nappe of the pile.

Marble and Carbonate Breccia (m)

A deformed tabular layer of marble and carbonate breccia (rauhwacke) occurs as the second highest nappe (Fig. 2) in the succession of nappes in the northern West Humboldt Range. The marble is a coarse-grained tectonite; the carbonate breccia consists of marble and calcarenite clasts in a matrix of calcite-quartz sand.

Gabbroic Rocks (g)

A small body of anorthosite and anorthositic gabbro intrudes Triassic pelite of the highest nappe in the northern part of the area of Figure 1. The thrust that bases the nappe cuts both the Triassic pelite and igneous rocks, indicating that the igneous rocks are allochthonous. Jurassic pelite in the subjacent nappe, however, is slightly metamorphosed within a few meters of the igneous rocks, indicating that final cooling was essentially synchronous with emplacement of the nappe occupied by the gabbroic rocks. The gabbroic rocks are an outlier of an extensive body of gabbro farther south in the West Humboldt Range, where evidence indicates that intrusion was concurrent with emplacement of the highest nappe of the pile (Speed, in prep.). A K-Ar age of hornblende from gabbro 11 km south of the body shown in Figure 1 is 163 m.y., and there is little question that the two bodies are coeval. An age of 163 m.y. is Middle Jurassic, probably Bathonian (late Middle Jurassic; Howarth, 1964).

[2] Use of the word "pelite" as a lithic descriptor connotes a very high proportion of intercalated silicate mudstone and siltstone which may locally grade to fine-grained hornfels or tectonite.

STRUCTURE

The objectives here are to provide an understanding of macroscopic structure of the Lovelock Formation as a context for stratigraphic discussion. Space does not allow analysis of data from minor structures that indicate the deformation and transport history of the formation; the latter data will be presented elsewhere, but some conclusions are mentioned here.

All of the rocks in the area shown on Figure 1 are allochthonous, and they are contained in a vertical succession of folded nappes[3] of which there is perhaps a total of seven in the northern West Humboldt Range. Thrust boundaries of the upper four nappes are shown in Figures 1 and 2. The numbers on thrust traces in Figure 2 indicate the vertical succession of nappe boundaries and the correlation of thrusts across eroded intervals. Thrusts are easy to trace where they juxtapose different lithologies, but they are difficult to follow where they separate bodies of similar rocks, especially Jurassic pelite. Thrusts at structural levels below those shown in Figure 2 are locally recognized just north of the area of Figure 1, but their traces cannot be continued as far south as Gypsum Mountain. The implication is, however, that Jurassic pelites structurally below the Lovelock Formation are allochthonous and may comprise several nappes.

The Lovelock Formation occurs in a pair of nappes, here called the "gypsum nappes," that lie between thrusts 3 and 4 of Figure 2. The gypsum nappes contain, as well, Jurassic pelite that is stratigraphically concordant to the Lovelock Formation. Boundaries of the gypsum nappes are located with certainty except along the west side of the southern nappe (Fig. 1) where the thrust apparently occurs within Jurassic pelite. The northern gypsum nappe overlies the southern one, such that thrust 4a on Figure 2 is younger than 4b. The lateral proximity of the two gypsum nappes and their occurrence at the same general structural level in the pile of nappes at Gypsum Mountain, however, suggest that the two gypsum nappes were originally continuous and were imbricated during or after emplacement.

Relations between folds in the Gypsum Mountain area (Fig. 1) provide a basis for interpretations of the tectonic history of the Lovelock Formation. Beds of the Lovelock Formation are deformed in three sequential fold sets, of which the first (set 1) consists of intranappe folds; the others (sets 2, 3) fold both beds and nappes. Major folds occur in all sets, but minor folds are recognized only in sets 1 and 2. Axial plane foliation and lineation are well developed in gypsum of the Lovelock Formation, but they are sparsely measured owing to the paucity of exposed gypsum rock. In contrast, penetrative structures are rare in carbonate rocks of the formation.

Within the gypsum nappes, the Lovelock Formation and its substrate occur in recumbent major folds (Fig. 2). The general orientation of tops of beds in the recumbent folds is indicated by arrows in Figure 2 as determined from cross-bedding in the lower member, where it is locally homoclinal. The recumbently folded members are at places truncated by the thrusts at the nappe bottoms, and such folds were clearly formed before final nappe emplacement. Pre-emplacement folds thus constitute set 1. Amplitudes of the major folds of set 1 exceed the width of outcrop of the Lovelock Formation, and it is difficult to determine the position and direction of the trace of axial surfaces of such folds. Analysis of minor folds believed to be cogenerate with the recumbent major folds, however, indicates that the original axial traces of set 2 folds are generally northerly, and their axes are essentially horizontal.

Folds of set 2 involve both the gypsum nappes and adjacent pelite nappes and are thus clearly later than the intranappe folds of set 1.

[3] Nappe: discrete allochthonous tectonic unit of mappable size, as modified from recommended usage of Dennis (1967). There is no constraint of detachment, displacement, or nature of internal structure. Structurally continuous rocks of the upper plate of a thrust fault constitute a nappe, but upper plates of extensive master thrust faults may comprise an assembly of nappes.

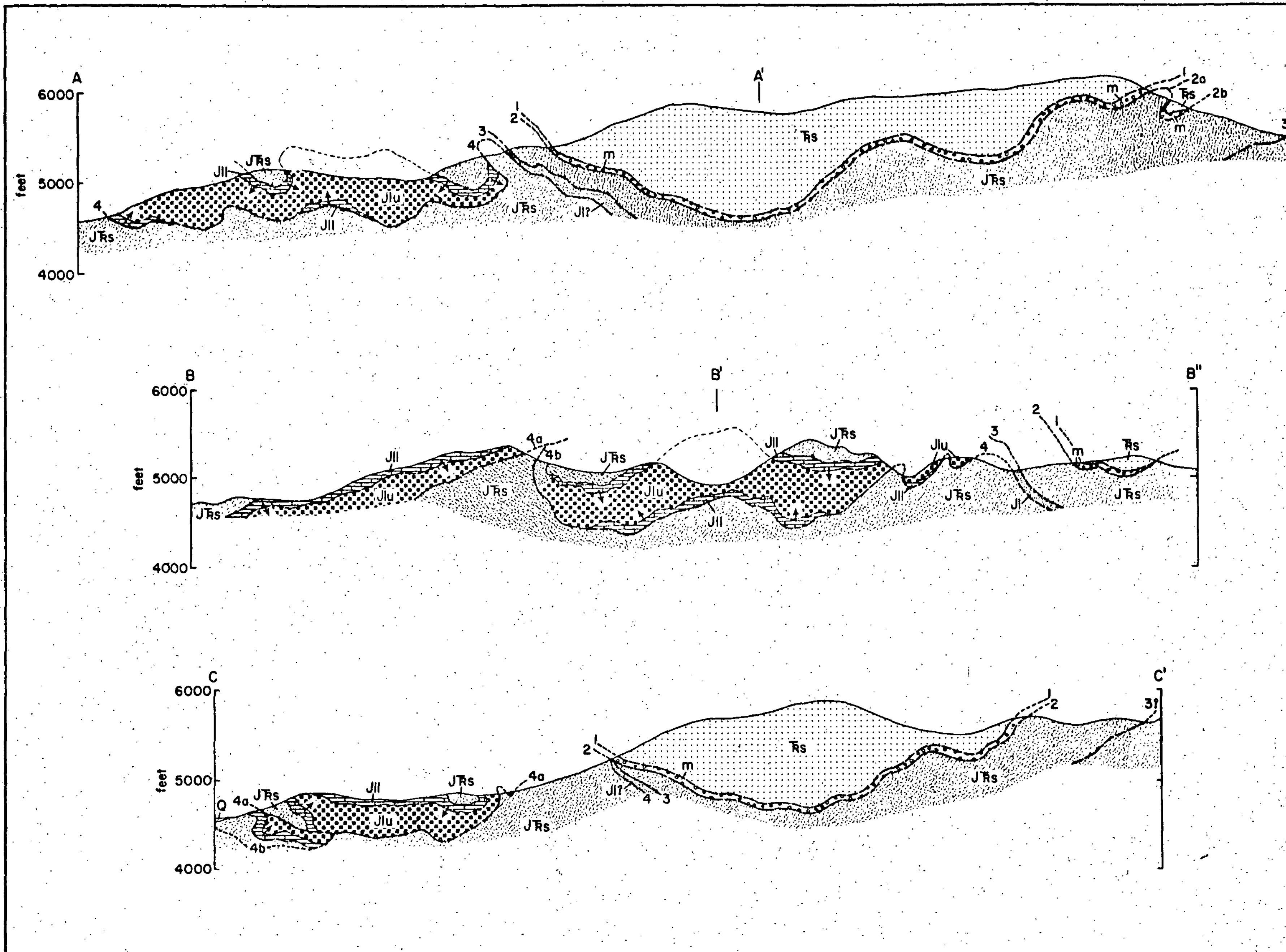

Figure 2. Geologic cross sections in the Gypsum Mountain area along traces shown in Figure 1. Symbols for lithic units and line weights for unit boundaries same as in Figure 1. Arrows in unit Jℓℓ indicate stratigraphic top in locally homoclinal segments. Numbers on thrust traces indicate generally downward sequence of nappe bottoms; 4 is bottom of gypsum nappe pair, subdivided to 4a and 4b where the separate nappes can be identified.

The major pattern of lithic units in the Gypsum Mountain area is largely due to set 2 folds, and folds of thrusts shown in the sections of Figure 2 are chiefly of set 2, except in the interval, BB′. Axial traces of folds of set 2, like those of set 1, are generally northerly, and axes similarly plunge shallowly. Figure 1 displays approximate axial traces of major folds of set 2, the variability of which is due to folds of set 3. Folds of set 2 comprise a spectrum of wave lengths, limb compressions (tightness), and inclinations of axial surface. The synform of the lowest harmonic recognized has a half wave length ≥ 2 km; its axial trace passes through Gypsum Mountain. The west limb of the synform exposes the lower nappes in the pile, including the gypsum nappes. Smaller wave-length folds of set 2 have axial planes that dip variably with easterly and westerly components. The variable dips indicate coaxial refolding or, possibly, remarkable divergence of the axial planes of the higher frequency folds on the limbs of the major folds[4].

Folds of set 3 consist of broad open folds with essentially easterly axial traces.

The coaxiality of the intranappe folds (set 1) and those of set 2, together with the generally similar variability of axial planes[5] of folds of the two sets, provides grounds for the proposition that the two sets were produced in a continuum of deformation rather than in tectonically discrete phases. The continuum hypothesis implies that nappe motion was adjunct to regional folding and was such that there was little rotation of set 1 axes relative to fold axes of set 2. Further, the occurrence of the Gypsum Mountain nappe pile in a major synform of set 2 implies that nappe transport was directed toward the developing synform. If the hypothesis is correct, the Gypsum Mountain synform was a nappe sink. The corollary is that nappe sources were upfolds, and if motion was generally normal to axes of folds of sets 1 and 2, such upfolds lay east and west of the northern West Humboldt Range. There is no clear interpretation of whether nappe motion was uphill or downhill, although the apparent lack of rotation of set 1 folds may be suggestive that the nappes were not detached gravity slides.

Dated gabbroic rocks (163 m.y. old) are deformed by set 2 folds and are essentially contemporaneous with emplacement of the highest nappe. Thus, deposition and deformation of the Lovelock Formation occurred during upper Lower Jurassic–Middle Jurassic time.

Evidence for the source and transport distance of the gypsum nappes is circumstantial. The hypothesis given in a previous paragraph suggests transport of the gypsum nappes either grossly east or west into a synclinal trough; the displacement would have been up to a half wave length of the major folds which regionally seems to be 4 to 9 km. The highest nappe in the West Humboldt pile probably came a few kilometers from the east or southeast, but there is no necessary association of the direction of displacement with that of the earlier gypsum nappes. Moreover, the multiplicity of nappes in the West Humboldt Range and their lithic homogeneity (chiefly Lower Jurassic rocks) suggest they had local derivation and small displacements, because rocks alien to those in the nappes and to Mesozoic rocks generally in the Carson region have not been mixed in the nappe pile. Although the arguments are not compelling, I believe the gypsum nappes were derived a few kilometers west or east of their current position and that such positions may be grossly taken as the depositional sites of the Lovelock Formation relative to the pelite substrate.

LOVELOCK FORMATION

Formation Characteristics

The Lovelock Formation comprises three informal members: a lower member of dark limestone, a middle member of limeclast conglomerate and microbreccia, and an upper member of gypsum and interbedded calcarenite. The formation is variably 25 to 200 m thick. Figure 1 shows the extent of the Lovelock Formation. It is locally differentiated in two map units, upper and lower + middle, the middle member being too thin to show separately. Elsewhere, the formation is undifferentiated either where tight folding makes the members difficult to show or where the formation consists chiefly of carbonate breccia. Such breccia is due largely to the accumulation of limestone fragments during dissolution of gypsum, as discussed later. Hence, much of the undifferentiated Lovelock Formation on Figure 1 originally consisted dominantly of the upper member. Erosionally isolated bodies of carbonate breccia and recrystallized limestone are called Jl? if they occur at the same structural level as the Lovelock Formation. The uncertainty in correlation is that, in principle, one or more of such bodies could represent the feather edge of some other nappe (or nappes) that lies between thrusts 3 and 4 as shown on Figure 2. The lithic similarity among breccias of the isolated bodies and that of the Lovelock Formation, however, suggests they are all evaporite solution breccias derived from the same gypsum unit whether structurally contiguous or not.

The Lovelock Formation lies conformably above Jurassic pelite. The formation top is erosional.

Age

The Lovelock Formation is undated paleontologically. Fossil material consists of pelecypod and cephalopod debris, but none is generically identifiable. Thus, age bounds are assigned to the Lovelock Formation on indirect evidence. The maximum age is Toarcian (late Early Jurassic), and the minimum is Bathonian (late Middle Jurassic).

The maximum age is based on youngest fossil ages in the Early Jurassic pelite. The pelite which lies conformably below the Lovelock Formation in the gypsum nappes has yielded no fossils, but, by lithology, it is unquestionably part of the predominantly Jurassic pelite unit (unit J̄R̄s). The gypsum nappes lie above pelite with Toarcian fossils, and they are overlain by an extensive nappe which also contains Toarcian fossils. Furthermore, rocks like those of the Lovelock Formation are nowhere interbedded with pelite in the Carson region, and pelite does not lie above the Lovelock Formation. The conclusion is that the Lovelock Formation is younger than any rocks in the pelite units. The minimum age of the Lovelock Formation is equivalent to the age of the gabbroic rocks (163 m.y.) which were intruded and cooled during emplacement of the highest nappe. The gypsum nappes, having been emplaced earlier, must contain rocks older than 163 m.y.

Lower Member

The lower member of the Lovelock Formation consists of 3 to 35 m of relatively homogeneous dark limestone. The limiting thicknesses occur where the unit is tectonically attenuated or repeated; about 25 m is the average stratigraphic thickness. The limestone consists largely of calcite micrite which is widely recrystallized to microsparite. Micrite is made up of calcite grains 5 μ

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[4] Wallace and Silberling (1962) published a reconnaissance structure section in the Gypsum Mountain area, approximately along section AA″ of Figure 2 of this paper. They were the first to recognize the nappe of Triassic pelite that is based by thrust 1 of my sections. They further show that strata equivalent to the Lovelock Formation are in a major fold overturned to the west. Their fold does not correspond in detail to folds delineated in Figures 1 and 2 of this paper, but it is presumably a generalized equivalent of folds of my set 2 that deform the southern gypsum nappe. They believed that the overturning indicates east to west overriding. Such motion is demonstrable at places in the West Humboldt Range, but at Gypsum Mountain, the spatial variability of inclination of axial surfaces of folds of set 2 makes difficult an interpretation of a general direction of overriding.

[5] Poles to axial planes of folds of sets 1 and 2 occupy similar great circles on equal-area plots. Such circles are spatially variable owing to rotation by set 3 folds. Set 1 poles are full circle, whereas those of set 2 occupy partial circles.

or less with an abundance of interstitial opaque material including pyrite and carbonaceous substances. In microsparite, the calcite grains are 5μ to 12μ, and they occupy a granoblastic texture which is interpreted to be of diagenetic origin. The content of opaque substances is lower in the microsparite than in the micrite. At places, micrite (or microsparite) grades to patchy sparite with calcite grain diameters of 100μ or less, generally in association with calcite spar veinlets which abundantly cut the lower member. Sparse anhedral quartz grains up to 60μ in diameter and a few platelets of white mica occur as isolated particles in the micrite and its recrystallized equivalents.

The micrite contains scattered to locally abundant laminae and thin beds of silty micrite, quartz calcsiltite, and quartz calcarenite. The coarser particles are calcite, quartz, and pyrite. Silty micrite and calcsiltite occur chiefly in plane laminae that sharply contact micrite. Calcarenite is generally in beds as much as 7 cm thick that contain sets of tangential cross-laminae whose maximum inclinations are about 15°.

The absence of fossils or skeletal debris in the lower member is noteworthy. Moreover, the existence of undisturbed plane laminae throughout the limestone indicates absence of bioturbation and suggests that benthonic faunas were lacking.

The lower member records a change, at least of local extent, in sedimentary environments from the deposition of fine silicate as represented by the Toarcian substrate to deposition chiefly of carbonate mud and only minor extraclastic components. The absence of fossils, predominance of mud, and darkness of the rocks, apparently owing to disseminated organic material, suggest a medium of largely stagnant, low-oxygen waters. The limited exposure of the Lovelock Formation prevents an understanding of the regional extent of the change of environments. The Lower Jurassic pelites, however, are characterized by their wide lithic homogeneity, implying lateral uniformity of their depositional basin. The lower member of the Lovelock Formation thus indicates either bypassing or cessation of the silicate flux and chiefly local generation of deposits.

At places, the lower member is strongly bleached and recrystallized to an average grain size of 1 mm. By its intensity and local occurrence, such recrystallization seems not to be of the same generation as the more pervasive micrite-microsparite-sparite series. The local intense recrystallization, moreover, affects the middle member (and perhaps the upper member) of the Lovelock Formation, whereas the microsparite-sparite recrystallization is at least partly earlier, apparently pre-middle member, as discussed later. Where patchy, coarse recrystallization occurs at the stratigraphic top of the lower member. Where more extensive, as at the northernmost and southernmost exposures of the Lovelock Formation, nearly the entire lower member is colorless coarse-grained meta-limestone. The absence of foliation in the coarsely recrystallized rocks implies that recrystallization was not produced by deformation of the Lovelock Formation. The distribution of such rocks suggests penetration of solutions and (or) heat downward from the top of the lower member.

Differences in conditions of recrystallization of micrite to microsparite and to meta-limestone are indicated by carbon- and oxygen-isotope data (Table 1). Ratios in microsparite are those of a marine limestone whose oxygen has equilibrated with light-oxygen water, as interpreted by Speed and Clayton (1974). Textures of the microsparites surely provide no suggestion that the recrystallization was at a significantly elevated temperature such that the oxygen exchange and grain reorganization in micrite ostensibly occurred during pervasion with meteoric water. In contrast, meta-limestone in the lower member contains remarkably lighter isotopic ratios than the microsparite and also textures which indeed suggest higher temperature recrystallization. Interpretations of the meta-limestone isotopic data by Speed and Clayton (1973) are that the temperature was sufficient (≥200°C) that decarbonation during recrystallization allowed concomitant lowering of δC^{13} during hydrothermal oxygen exchange. Thus, meta-limestone appears to have resulted from recrystallization due to hydrothermal fluid that entered the lower member sporadically from its top.

TABLE 1. CARBON- AND OXYGEN-ISOTOPE RATIOS OF LIMESTONES OF THE LOWER MEMBER OF THE LOVELOCK FORMATION*

Rock	δC^{13}(PDB) ‰	δC^{18}(SMOW) ‰
Microsparite	+0.6	18.2
Coarse-grained colorless meta-limestone from 0.5 m below top of lower member	-5.3	7.2

*Analyses courtesy of R. N. Clayton, University of Chicago.

Middle Member

The middle member of the Lovelock Formation is predominantly limeclast conglomerate and sedimentary breccia together with lesser amounts of calcarenite and red silicate mudstone and sandstone. The thickness of the middle member varies laterally from 3 to 20 m. The contact of the lower and middle members is largely conformable, but locally an angular unconformity exists.

The coarse-grained fragmental limestones of the middle member are of two distinctive lithic types, described below as calc-conglomerate and sedimentary calc-breccia. Conglomerate consists chiefly of a massively bedded framework of subangular to subrounded limestone clasts. A few thin lenses of calcarenite exist in the conglomerate. There is at most places a modest preferred shape orientation of clasts. The clasts are equant to ovoid; axials ratios ≤2. Maximum clast lengths are between 5 and 15 cm.

Clasts are largely micrite, laminated micrite-quartz calcarenite, and micrite variably recrystallized within the micrite-sparite spectrum. Many limeclasts contain veins which are truncated by clast margins. Clasts composed entirely of coarse-grained vein spar exist. Sparse fragments of calcarenite and pebbly calcarenite in the conglomerate are lithologically like the conglomerate matrix and are interpreted to be of synsedimentary derivation.

The calc-conglomerate matrix is fine- to medium- grained calcite-quartz–white-mica sand. The quartz content of the matrix is inversely proportional to grain size and does not exceed about 30 percent. At places, sand of the matrix grades to lensy thin beds of calcarenite or pebbly calcarenite.

Calc-conglomerate occurs chiefly at the base of the middle member and is overlain conformably by sedimentary calc-breccia which contains thin interbeds of finer grained calc-conglomerate. The clast population of the conglomerate largely contains the same lithic spectrum as does the lower member. The lithic similarity and spatial relations clearly indicate that the lower member was the pebble source. The framework structure of most of the conglomerate and quasi-equant pebble shapes and modest rounding suggest that the micrite of the lower member was at least moderately lithified by the time it was eroded.

The conglomerate is of variable thickness, and it wedges out at places. Where the conglomerate is absent, sedimentary calc-breccia lies directly on the lower member with modest angular unconformity. At such places, the lower member was variably eroded with or without uplift before deposition of the breccia. The relation indicates such places were likely sources of conglomerate pebbles. Exposure does not allow clear assessment of whether the unconformities are shallow channel bottoms or eroded surfaces of tilted micrite beds. It is thus possible that the conglomerate could be fluvial or wave-laid or both.

The second distinctive fragmental rock type in the middle member is sedimentary calc-breccia which generally lies above the conglomerate (Figs. 3, 4, 5). The breccia contains thin interbeds of

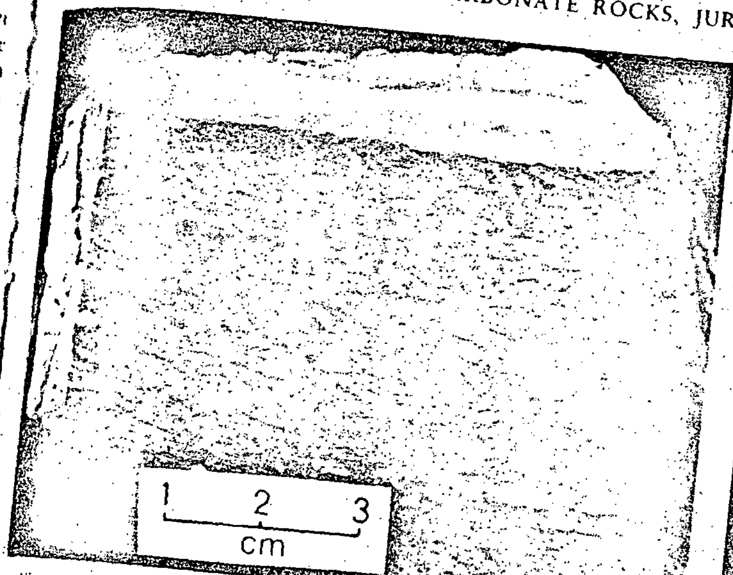

Figure 3. Calc-breccia of micrite (dark) and sparite (white) granules, outsize angular microsparite clast (at top), dark sinuous mudchips, generally dark pellets and superficial ooids. Matrix of fine-grained calcite-quartz sand. Generally unaltered hydrothermally. Polished slab.

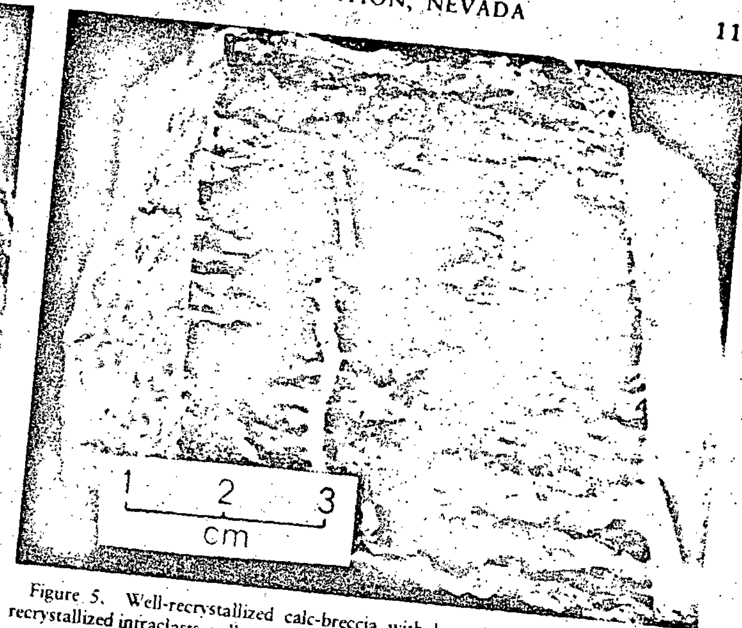

Figure 5. Well-recrystallized calc-breccia with large layers (white) of coarsely recrystallized intraclasts, pellets, and so on. Polished slab.

Figure 4. Moderately hydrothermally recrystallized calc-breccia with same clastic components as specimen in Figure 3. Note relict streaks of organic (dark) material perpendicular to clast elongation. Lime clasts generally more bleached than in Figure 3. Polished slab.

limestone conglomerate and calcarenite and laterally interfingers with red silicate detrital rocks. The thickness of breccia is between 0.5 and 12 m. The lithic characteristics of the sedimentary breccia are the high angularity and shape elongation of certain clastic components and the generally finer grain size than that of the conglomerate.

The sedimentary breccia comprises a framework of moderately size-sorted diverse calcitic particles in beds a few centimeters to a meter thick. The particles are chiefly granule-size micrite and sparite limeclasts and irregular platy carbonate fragments together with minor pellets, coated grains, and skeletal fragments. Particle diameters are between 0.1 mm and 2 cm.

Limeclasts consist of micrite and recrystallized and veined equivalents as in the conglomerate. Anhedral quartz silt occurs sparsely in the clasts; in the coarsest-grained fragments, chalcedony locally replaces calcite. The clasts are equant to ovoid and have axial ratios of <2. Each of the limeclast types occurs as both rounded and angular fragments. There is no stratigraphic differentiation of limeclasts by degree of recrystallization. It would thus appear that the conglomerate and breccia have the same limeclast source—namely, the lower member.

An apparent difference in the two clast populations, however, is that the proportion and perhaps grain size of sparite fragments is greater in the sedimentary breccia than in the conglomerate. In fact, many sparite clasts are coarser grained than rocks of the lower member except where the lower member has been coarsely hydrothermally recrystallized. Yet, it is clear that the coarse sparite clasts are depositional. The implication is that the source rocks of granule-size clasts were more highly recrystallized than the pebble source, which was probably more proximate to the preserved depositional site.

Principal framework components in much of the sedimentary breccia are dark irregular platy calcareous fragments, hereafter called "chips," whose squarish broad faces vary from 0.5 to 1 cm on a side. Chip thickness is 1.5 mm or less, generally in proportion to their diameter, and their profiles are variably undulous and planar (Figs. 3 through 6). Some have curled ends or are convolute with the matrix. Chips may locally constitute as much as 70 percent of the breccia.

The mean size of the chips is proportional to the size of associated limeclasts within different beds of the breccia. The chips, moreover, are discrete (unattached to other grains), and their broad faces are moderately well aligned in the bedding plane. The observations strongly indicate that the chips are detrital and that they were cosorted with the limeclasts. Some chips partially conform to the surface of a limeclast which, together with the curled ends and local convolutions, implies the chips were nonrigid on deposition. Others, however, have angular, rectangular ends, suggesting they are fragments of once larger grains.

The chips are composed of granoblastic sparry calcite in the grain size range of 10μ to 100μ. Some are homogeneously coarse or fine; others have microspar at the margins grading inward to coarser spar. Chips are rich in organic matter relative to lithic clasts and hence are darker (Figs. 3 through 6). Coarser grained chips are clearer, but they generally contain relict organic matter in columns perpendicular to chip lengths (Fig. 4). Replacement chalcedony occurs in a few.

L. C. Gerhard kindly examined specimens of the calc-breccias to assess a suggestion that the chips are algal. He finds no morphologic evidence or internal structure in the chips to establish the presence of algae (notably chlorophytes) which could, in principle, contribute coarse skeletal debris. Moreover, Gerhard reports (1973, written commun.) that no Jurassic chlorophytes are known which bear morphologic resemblance to the chips. The well-aligned, vaguely bounded columns of dark organic material in chips are not skeletal structures, because parallel columns exist in partly recrystallized micrite clasts (Fig. 5).

Because the chips are evidently nonskeletal, they must be presumed to be organic-rich micrite laminae or equivalently, carbonate mudchips. Evidence of flexibility during deposition indicates that at least some chips were soft and incompletely lithified. Moreover, their apparently fragile character and angularity suggest the chips were not transported a great distance. The chips are evidently intraclasts, and the most likely origin of such mudchips, as suggested by L. C. Gerhard, was as dessication clasts. The steady production, erosion, and marine deposition of the mudchips apparently required an intertidal environment. The mud surface was ostensibly a seal to atmospheric oyxgen such that organic matter was at least partly unoxidized in the mudchips. There is no relict internal structure in the mudchips suggestive of original algal binding agents.

Sparser clastic framework components in the breccia are pellets and various coated particles with diameters between 0.1 and 0.6 mm. Pellets are homogeneously micrite; no algal components have been resolved. Some pellets have a single very thin concentric rim. Many with or without rims have drusy rim cement. Superficial oöids or multicoated pellets have as many as four coatings; such particles are less abundant than pellets, and oöids are yet more scarce. Coarse calcite crystals of probable skeletal origin occur within single or multi-coatings. A few veined pelletal aggregates exist. It is important to note that the pellets and coated grains are largely spherical, thus unstrained, in locally planar segments of the middle member. It is thus clear that the fabric of the sedimentary breccia is not tectonitic.

L. C. Gerhard (1973 written commun.) observed sparse and poorly preserved fossil fragments in the calc-breccia. He found pelecypod and cephalopod debris, and possible ostracodes. Such fragments indicate that the calc-breccia is marine. The shell fragments as places have micritic coatings and algal(?) borings as described by Bathhurst (1966).

The coarser components of the sedimentary breccia form a compact framework whose interstitial volume is less than 10 percent. The close packing is obviously due to the subparallel stacking of the carbonate mudchips and their draping around limeclasts. The interstices contain variably calcite mud and sand-size calcite-quartz-pyrite. The sand matrix is distinguished by its higher quartz proportion and abundant pyrite.

Red silicate mudstone and sandstone and pebbly equivalents occur in a generally discrete subunit in the middle member of the northern gypsum nappe; such rocks are absent in the southern gypsum nappe. The silicate rocks are bounded by conformable contacts with sedimentary breccia which, moreover, occurs as laterally tapered fingers and isolated depositional lenses in the silicate rocks. The silicate rocks have a maximum thickness of about 5 m; their thickness is proportional to the thickness of the member. The rocks are predominantly kaolinite mud containing various proportions of quartz silt or sand, detrital coarse white mica flakes, and finely disseminated iron oxides. Sorting is generally poor, and where it can be resolved, bedding is plane.

At places, the silicate rocks are pebbly mudstone or sandstone; the clasts are commonly rounded, ill-sorted, and as coarse as 1 m in diameter. The most abundant clasts are dark micrite and variably recrystallized equivalents as in the fragmental carbonate rocks.

Figure 6. Laminated gypsum-calcarenite; right side of specimen is a polished surface where darker bands are gypsum rich, and white bands are more calcitic.

In both the calc-conglomerate and calc-breccia of the middle member, two phases of recrystallization in the intraclasts can be recognized. The earlier phase corresponds to the production of microsparite and sparite in the lower member and is at least partly pre-middle member. The later phase involved strong hydrothermal recrystallization, and by the proportionate degrees of such alteration in the lower and middle members, the hydrothermal event was post-middle member.

The temporal relations of the first recrystallization and deposition of the middle member are interpreted from the juxtaposition of micrite and sparite clasts and the existence within clasts of veins cut by clast boundaries in conglomerate and breccia at places where effects of the later recrystallization are apparently absent. Further, in such rocks, the matrix contacts lithic clasts sharply and matrix carbonate is not evidently texturally different whether it contacts micrite or sparite clasts, implying the variable recrystallization within lithic fragments is pre-clast. The relations thus support evidence from the morphology of clasts derived from the lower member that they were lithified before erosion.

The recrystallization history of the carbonate mudchips in the calc-breccia is more uncertain than that of the lithic clasts. The microsparite and sparite of the mudchips are zoned in many chips such that the coarsest grains are in the chip center. The zoning indicates recrystallization after fragmentation. Boundaries of chips, however, are sharp with respect to the matrix, suggesting that recrystallization occurred prior to deposition. Thus, it is possible that the mudchips recrystallized during dessication and transport, possibly having started as aragonitic mud. On the other hand, aragonitic mudchips could conceivably have been deposited and then recrystallized to calcite without interaction with the calcite sand of the matrix.

The later phase of hydrothermal recrystallization is patchy in the middle member, as is also the case in the lower member except at the northern and southern ends of the outcrop area of the Lovelock

Formation. There, a high degree of recrystallization pervades the formation and at places makes the fragmental character of the middle member difficult to recognize. Figures 3, 4, and 5 illustrate the creation of lensy patches of colorless coarse calcite (meta-limestone) from clasts, mudchips, and matrix in calc-breccias during progressive alteration. The dark organic material in the mudchips is preferentially retained relative to that in the limeclasts, but the ultimate product is a completely bleached rock. The organic carbon removed during hydrothermal recrystallization of the lower and middle members may play an important role in generation of light-carbon marble in the upper member and rauhwackes of the Carson region (Speed and Clayton, 1974).

Sedimentology of the Middle Member

The middle member of the Lovelock Formation consists almost entirely of deposits of allochthonous abraded and accretionary or aggregational carbonate particles. In-place biogenic components are absent. The abraded particles are largely coarse lithic particles, mudchips, and fine-grained calcite-quartz sand. Accretionary and aggregational grains are coarse sand-size pellets, oöids, and skeletal particles. The member also contains minor extrabasinal silicate and quartz sand of presumed terrigenous origin.

Perhaps 50 percent or more of the middle member consists of limeclasts of micrite and variably recrystallized equivalents. Coarse clasts are in the calc-conglomerate, the granule fraction is in the calc-breccia, and the full size range occurs in the red siltstone. The limeclast population constitutes a homogeneous and continuous lithic spectrum that corresponds closely to the spectrum of limestones of the lower member. The conclusion is that limeclasts of the middle member were derived solely from the subjacent member.

Dark limestones that exist sparsely in Jurassic pelites below the Lovelock Formation could in principle have served as a limeclast source. Such limestones, however, are sandy and abundantly stromatolitic and are not easily confused with the limestone of the lower member of the Lovelock Formation. Moreover, it is difficult to conceive of the limestone of the pelite sequence as a source for the limeclasts of the middle member because of the absence of clasts of resistant sandstone and siltstone which volumetrically predominate over dark limestone in the Jurassic part of the pelite sequence.

Evidence is lacking for dating the hiatus between the lower and middle members within the age limits of the formation. Broadly considered, however, the events which changed the environment from silicate to micrite deposition at the base of the Lovelock Formation were likely to have been related to those which ultimately provided conditions for gypsum (or anhydrite) saturation in marine waters and deposition of the upper member. Given such continuity, the clastic middle member was surely related to the same events, and the limeclasts would be truly intraclastic (Folk, 1959; Wolf, 1960).

Clast morphology and textural relations with the conglomerate matrix indicate that the limeclasts were at least moderately lithified before transport. Lithification was presumably concurrent with the recrystallization of micrite in the lower member to microsparite and sparite. The question arises as to how such recrystallization could have occurred in a scheme of quasi-continuous evolution of the Lovelock Formation. Because the early recrystallization of micrite in the lower member apparently involved oxygen-isotope exchange between calcite and meteoric water, there must have occurred partial or total emergence of the micrite after deposition. The early recrystallization was thus a fresh-water diagenesis. Moreover, it follows that emergence provided the local sources of lithified limeclasts for deposition as calc-conglomerate of the middle member.

Limeclasts in the conglomerate and breccia of the middle member underwent modest lateral motion as indicated by their sorting, rounding, and packing. The lithic homogeneity of the pebble population, the spatial coupling of the conglomerate to its clast source, and the variability of thickness of the conglomerate argue effectively, however, that pebble transport was short and that extrabasinal input to the conglomerate was nil. I envision that after exposure and diagenesis of the micrite sediments of the lower member, wave and (or) fluvial erosion dissected such rocks and created an irregular terrain. Fluvial erosion may have been important in local clast transport, but postulated streams were surely not connected to major terrestrial drainage systems that would have contributed extraclastic debris.

The transition in the middle member from conglomerate to calc-breccia records the deposition of granule-size intraclasts and near exclusion of pebble and coarser sizes. The transition implies lateral and (or) vertical erosional retreat of the irregular limestone terrain and a change to a lower flow regime. Such changes were concurrent with the first recognized deposition of carbonate mudchips, coated grains, pellets, and skeletal particles. This particle assembly was derived from subenvironments that are common to shallow carbonate banks with laterally variable flow regimes. Mudchips were ostensibly dessication clasts on intertidal flats, oöids were probably generated at places of strong tidal flow or wave motion, and pellets were more generally lagoonal (Sanders and Friedman, 1967). Deposition of the calc-breccia thus reflects either the construction of a carbonate bank or perhaps the first preservation of allochthonous bank-generated particles. I postulate that erosion of the exposed, initially irregular micrite terrain, coupled with deposition of the calc-conglomerate, smoothed the surface and created a lower relief littoral environment with much enhanced particle circulation. The flow regime during deposition of the calc-breccia was reasonably strong, however, because of the thorough mixing of various particles and the absence of autochthonous micrite laminae whose presence would indicate flows locally too weak to rip off bottom mud.

Fine-grained, calcite-quartz sand occurs in the middle member as generally discrete calcarenite beds or as the matrix of the coarse fragmental rocks. Such sand thus appears to have existed throughout the deposition of the middle member. The calcite fraction consists entirely of abraded particles, apparently of lithic origin. It is reasonable to assume that during deposition of the conglomerate, lithic carbonate sand accumulated in quieter waters, perhaps offshore of the eroding terrain. The quartz component could have been partly derived from the micrite and, perhaps as well, by longshore transport. The suggestion is that such sands formed the bank margin once the micrite platform was smoothed by erosion.

Beds of red mudstone and sandstone and quartz silt and sand in the matrix of fragmental carbonate rocks and calcarenite beds indicate a terrigenous input into the postulated carbonate bank environment. Matrix quartz is ubiquitous and implies a steady but small influx. The red silicate rocks, however, have characteristics which suggest emplacement as a single pulse. The rocks are poorly sorted except where they grade into sedimentary breccia; they occupy a single stratigraphic interval in a restricted area (northern nappe only). Lastly, they contain a wide spectrum of sizes of matrix-supported clasts, some of which are intraclastic and some extrabasinal. Pickup and transport of the clasts would seem to require significant velocity and density of the fluid. The characteristics suggest that the red silicate rocks were emplaced as a mudflow into the depositional site of the sedimentary breccia. Local reworking produced some bedded silicate rocks and interfingering silicate and carbonate layers along the margins of the mudflow. Regardless of mode of emplacement, the red silicate beds indicate breachment of a barrier (solid or fluid) which had apparently prevented large terrigenous input during preceding deposition of the middle member.

Upper Member

The upper member of the Lovelock Formation is made up of gypsum and quartz calcarenite which are interlayered on various scales from lamination to homogeneous beds 2 to 3 m thick. The member also locally contains bodies of calcarenite breccia and of very coarse grained tectonitic marble. The contact of the upper and middle members is placed at the top of the sedimentary breccia; the basal rocks of the upper member are conformable fine-grained thin-bedded calcarenite. The boundary is thus a sharp change from coarse fragmental carbonate rocks to carbonate sandstone; because calcarenite occurs in the middle member as matrix and as sparse discrete beds, the transition essentially records the cessation of deposition of coarse particles. The top of the upper member is apparently erosional, and it is inferred that beds of the upper member are the last marine deposits of their stratigraphic succession.

The upper member presents difficulties in stratigraphic and structural analysis because thick surficial efflorescent gypsum coats much of the surface underlain by the member. A qualitative appreciation of the nature of the unit can be gained from mine faces and trenches, but spatial variability is impossible to determine at the surface. Beds of the upper member are in isoclinal folds of set 1. Axial planes of the isoclines are minor-folded on northerly axial traces in harmony with the megascopic refolding of the major recumbent folds in the nappes (Fig. 2). Calcarenite beds in fold limbs occur commonly in boudinage.

The original stratigraphic thickness of the upper member is unknown. The preserved thickness is uncertain but is perhaps of the order of 100 m.

Layered rocks of the upper member are various assemblages of gypsum-calcite-quartz-white mica. Laminated rocks are abundant, and they occupy stratigraphic intervals as much as several meters thick. The laminae are 0.1 to 5 mm thick (Fig. 6). They are alternately homogeneous gypsum in anhedral mosaics and gypsum-calcite-quartz-mica. Calcite and quartz occur in generally discrete equant grains between 0.1 and 0.2 mm in diameter at a relatively constant ratio (calcite-quartz grains) of 30. White mica is in trace quantities. Very thin calcite-quartz laminae are essentially monoparticle layers of which gypsum is perhaps 50 percent. As the thickness of the calcite-quartz laminae increases the proportion of gypsum diminishes, and the calcite and quartz grains are slightly coarser. Thin-bedded rocks are apparently more plentiful than the laminated ones. Here, gypsum containing disseminated granular calcite occurs in beds a few centimeters to a few tens of centimeters thick. The gypsum beds alternate with calcite framework quartz-calcarenite beds 1.5 cm thick which contain little or no gypsum. Still thicker beds are exposed locally; they consist of homogeneous coarse-grained gypsum up to 3 m thick and cross-bedded calcarenite or calcitic quartz sandstone over intervals 5 m thick.

Thick-bedded calcarenite occurs at the base of the upper member, but there appears to be no other preferred stratigraphic succession among the layered rocks of the upper member. Discrete calcarenite beds are estimated to constitute about 25 percent of the upper member. Inclusion of calcite and quartz in laminae and disseminated in gypsum would increase the nonsulfate quantity another 10 to 15 percent.

Gypsum associated with calcite-quartz in laminae or thin beds occurs in a mosaic of anhedral grains averaging about 50μ in diameter. In more homogeneous gypsum layers, however, abundant euhedral gypsum grains up to 5 mm in length occur with smaller anhedral grains. Some coarse gypsum rocks are nearly panidiomorphic. A few coarse gypsum euhedra intersect laminae of calcite-quartz-mica and include the nonsulfate grains of the lamination without modification. As indicated below, calcite, quartz, and mica are believed to be clastic particles. The textures suggest that the coarse gypsum grains have grown at the expense of former finer grained anhedral gypsum which commonly is associated with the nonsulfates. Moreover, there is a preferred orientation of (001) of coarse gypsum grains which parallels axial planes of minor folds as well as a grain-shape lineation. The coarse gypsum thus appears to be postdepositional and probably is synkinematic with first deformation, ostensibly during the creation of the major recumbent folds before or during nappe transport.

One would predict that sulfate in a tectonic and hydrothermal environment like that of the Lovelock Formation would have undergone multiple dehydrations and hydrations in its history. It thus may be questionable whether recrystallization fabrics should reasonably be assigned to deformation early in the formation's history. Anhydrite, however, is currently unrecognized in surface rocks of the Lovelock Formation, and to my knowledge, it has not been found by drilling. Textures provide no evidence for replacement of anhydrite by gypsum or the former existence of nodular anhydrite.

The calcite-quartz-mica laminae and calcarenite beds are well-sorted deposits of fine-grained and very fine grained sand. The interpretation is based on the occurrence of discrete, equant grains in laminae, the similar size of quartz and calcite, and the low-angle cross-bedding. Biogenic, pelletal, or oölitic grains are apparently absent in these rocks.

Gypsum and calcarenite of the upper member were deposited conformably and in probable temporal continuity with fragmental rocks of the middle member. The concomitant disappearance of mudchips and coated and skeletal particles from the section with the onset of evaporite deposition suggests deepening and decrease in circulation coupled with increased salinity. Such changes may have been in conjunction with landward transgression of the environments represented by the middle member. The accumulation of locally thick pure sulfate implies precipitation in standing water and the existence of a barred basin. Alternation of gypsum with calcarenite that includes quartz of ostensible terrigenous origin indicates, however, some degree of particle transport. The laminated rocks (Fig. 6) surely indicate periodicity, tidal or diurnal, of deposition; thin-bedded rocks might similarly represent lower frequency periods. The rocks are not dune accumulations, judging from the absence of appropriate structures; the evaporite is not supratidal, because it forms the rock framework and does not apparently disrupt calcite-quartz beds (Kinsman, 1969). The deposition of evaporites over littoral deposits of the middle member indicates subsidence of at least 100 m of the evaporite basin relative to its marine barrier.

Calcarenite of the upper member is similar in composition and grain size to that in subjacent members except for a possibly finer mean size. The implication is that calcite-quartz sands were continuously generated during the history of the Lovelock Formation. If such sands constituted a bank margin at the onset of deposition of the middle member, they may have contributed to the barrier that existed during evaporite precipitation.

Marble in the Upper Member

The upper member contains bodies of calcite marble which are clearly postdepositional. The existence of marble in the Lovelock Formation is an important link in the interpretation of the origin of rauhwackes in the Carson region.

Marble consists of coarse-grained (1 to 5 mm) calcite with a granoblastic texture, and at places, a megascopic grain-shape foliation and lineation. Colorless marble at places contains interlayers of gray to black finer grained crystalline calcite rock which gives strong emission of H_2S when broken. Where layered synclinal folds are evident in the marble. Rocks classed as marble are clearly coarser in grain size than the sparites, and they are both coarser grained and far more uniformly granoblastic than the hydrothermally altered meta-limestone below the upper member.

Bodies of marble occur in the upper member in the northern and southern nappes. An extensive but thin (0.5 to 5 m) body of tectonitic marble lies along the thrust contact of the upper member and rocks of the pelite sequence over a distance of about 1 km in the northern nappe. Here, a zone of breccia separates gypsum from the marble. The position of this marble body is suggestive that its origin may be connected with thrusting. Another body of marble of outcrop dimensions 30 m on a side is surrounded by gypsum. Marble is brecciated at the contact, and gypsum fills the cracks. A third body of marble, about 100 m long, occurs at the base of the upper member. The body is about 20 m thick and is apparently overlain by gypsum. The marble contains intercalated cross-bedded calcarenite in layers which parallel the top of the middle member. The relations suggest that gypsum was removed and coarse calcite was emplaced. The calcarenite and adjacent carbonate rocks of the middle and lower members are not recrystallized to grain sizes comparable to those of the marble, and the origin of the marble is problematic. Similar rocks occur in the rauhwackes of the Carson region, and an origin by calcitization of gypsum is proposed on structural and isotopic grounds (Speed and Clayton, 1974).

Breccia in the Upper Member

Stone and others (1920) observed in underground workings that breccia was abundant near the base of the gypsum. Carbonate breccia is in fact widespread in the upper member of the Lovelock Formation in sporadic bodies which are topographically (not stratigraphically) below gypsum-bearing sections.

The simplest breccias are monolithologic calcarenite bodies. They consist variably of intervals 1 m thick of undisrupted folded thin-bedded fine-grained calcarenite which grades to fragmented but unrotated calcarenite beds to framework breccia of rotated fragments and (or) to pebbly sandstone. The matrix of the fragmental rocks is well-sorted fine-grained calcite and quartz sand; the same sand-size components constitute the framework of the pebbly sandstone. This type of breccia clearly has correlative degrees of fragmentation and of sand to lithic clast ratio.

The prevalent monolithologic calcarenite breccia within the spectrum is a framework of co-oriented bed segments without size sorting and with calcite-quartz sand matrix. Intervals as much as 1 m thick of clast framework may alternate with matrix-rich layers.

Calcarenite clasts in breccias have the same grain-size spectrum (very fine grained to nearly medium grained) and bed thickness range as does calcarenite in place in the upper member. The breccias are unquestionably accumulations of such rocks. Where calcarenite is interbedded with gypsum in the upper member, breccia is absent, thus implying that intraclastic sedimentary breccias were not a normal mode of calcarenite deposition. Conversely, the absence of gypsum in calcarenite breccias and the similarity of calcarenite breccia clasts to calcarenite in the gypsum section strongly indicate that the breccia originated by solution of sulfate and gravitational accumulation of the undissolved fraction. Solution of sulfate in the laminated and thin-bedded rocks which contain largely discrete calcite and quartz sand grains would provide free sand for the breccia matrix and unbedded pebbly sandstone. The preservation of segments of continuous calcarenite alternating with fragmented but well-oriented calcarenite and with pebbly sandstone indicates a steady, uniform withdrawal of sulfate from the rocks and concomitant compaction of the insolubles. The final compacted products reflect their initial sulfate content. That is, in the absence of sulfate, no breccia is developed; interbeds of sulfate and calcarenite yield calcarenite breccia; and where calcarenite beds were lacking, only disseminated calcite-quartz sand accumulates. Compaction solution breccias are clearly different from collapse breccias in that motions are nonaccelerative such that original stratigraphic ordering is better reflected in the compacted products. Moreover, cavities would not be created in steady compaction, and lateral sorting and transport by subsurface streams would, in principle, be absent. Stanton (1966) found evidence that certain solution breccias in Montana accumulated by compaction rather than collapse.

Large masses of polymict breccia occur in the upper member in apparent association with certain structures. The clasts are largely calcarenite, as in the monolithologic breccia, but they are mixed with clasts of other lithologies along the borders of the breccia body.

The largest body of polymict breccia occurs in the northernmost outcrops of the Lovelock Formation, and together with a coextensive belt of marble, it comprises the upper member for about 1 km south of the northern margin of Figure 1. Gypsum is absent over this interval. Here, marble forms the margin of the formation, and the east side of the marble belt is the thrust which begins the overturned Lovelock Formation over Jurassic pelite. Breccia occupies the 10- to 20-m-thick zone between marble and the middle member. The breccia is chiefly calcarenite with calcite-quartz sand matrix, but isolated angular blocks of marble as much as 1 m across occur sporadically in the breccia. Within a meter of the contact of breccia and marble, the breccia consists largely of marble clasts, but it contains the same sand matrix as in calcarenite breccia. In the vicinity of some major fold hinges, probably of set 2 folds, the breccia has highly stretched clasts ostensibly indicating that the breccia is pre–set 2. South from the sulfate-free zone, the breccia grades to bedded gypsum and calcarenite except at the formation top, here upside down. A thin marginal belt of marble and marble-calcarenite breccia and calcarenite breccia totaling about 3 m thick continues south between the thrust on the east side and the gypsum-calcarenite of the upper member for about ½ km.

The marble was clearly formed before the breccia. In the gradational zone, however, the thickness of the breccia and the frequency of marble clasts are proportional to the thickness of the marble, possibly suggesting a genetic connection of marble and breccia. The thickness of the breccia is also inversely proportional to the thickness of the gypsum, and significantly, to the thickness of the formation as a whole. The latter relations together with the similarity of calcarenite clasts and sand of the polymict and monolithologic breccias surely indicate that the polybreccias are also of solution origin. The problem is—how did large fragments of marble get into the calcarenite breccias?

A possible solution to the postulated transfer of marble clasts during breccia formation is that cavities and subsurface flows existed in the particular polybreccia under discussion. Evidence for open spaces is that some of the finer grained calcarenite breccia is size sorted, and the sand of associated pebbly sandstone is modestly bedded. The polybreccia thus differs from the monolithologic type which exhibits no recognized sorting. The polybreccias in general, however, have characteristics better explained by compaction than collapse. In particular, there are no assemblies of large mixed fragments including a concentration of marble clasts as might be predicted from the collapse of a cavern roof. I think that mechanical transfer is an unlikely origin for the marble clasts.

A preferred origin is that the marble blocks are more or less in place, and they simply compacted during sulfate solution, along with calcarenite. The implication is that calcitization of gypsum, as referred to earlier, occurred within the upper member as well as at its margin. The calcitization, moreover, was earlier than dissolution of sulfate. Support for internal calcitization obtains from the occurrence of a large marble body, previously described, completely surrounded by gypsum. Conceptually, dissolution of gypsum and precipitation of calcite could have been concomitant as a replacement process. Calcite precipitation was perhaps then arrested by change of solution composition, but sulfate continued to be dissolved, thus producing breccias with marble fragments. The covariant thicknesses of the breccia and continuous marble as well as the other proportionalities support the idea.

Another type of polymict breccia occurs in the upper member, chiefly in the hinge regions of major folds. As with the first type, monolithologic calcarenite breccia is predominant, but near the contact of the upper and middle members, clasts of carbonate rocks from the middle member are mixed with the calcarenite clasts in a zone a few meters thick. A few clasts of highly altered microdiorite were observed in these polymict breccias. Such breccias are largely massive and lack preferred fragment orientation; the matrix is sandy calcite-quartz-pyrite. The massive breccia, however, locally grades laterally to unbedded pebbly sandstone with good pebble-preferred orientation. The lateral gradation of breccia to sandstone suggests at least local collapse and lateral transport of finer particles by waters flowing through a cavity network.

The association of breccias containing clasts of the upper and lower members and fold hinges is suggestive of tectonic brecciation as a factor. One hypothesis is that hingeward flow of sulfate and its associated bedded and disseminated carbonate occurred during major isoclinal folding. The more competent middle member fractured during flexure, and materials of the upper member invaded the fractures. Subsequent solution of sulfate rendered a zone of mixed carbonate clasts in the vicinity of the contact of the upper and middle members.

If correct, the hypothesis indicates that solution brecciation was post–set 1 folds. The occurrence of other breccia bodies in the upper member topographically below gypsum but independent of any stratigraphic control strongly supports the development of *recumbent major folds before breccia formation.* The existence of fragments of igneous rocks indicates a period of intrusion which is postgypsum but prebreccia. The age of the solution breccias is thus not certain, but if the postulated calcitization of sulfate and dissolution of sulfate were in fact penecontemporaneous, the solution breccias were formed during or shortly after emplacement of the nappes in which the Lovelock Formation occurs. The reasoning is that elsewhere in the West Humboldt Range, extensive marbles (which are believed to be calcitized sulfate) and calcarenite breccias are intruded by gabbroic rocks of Middle Jurassic age. It is probable that the upper member of the Lovelock Formation was the precursor to all of these marbles and breccias.

Diagenetic and Epigenetic Events

Each of the members of the Lovelock Formation is affected by one or more stages of textural reorganization, the conditions of which are important in interpretations of the evolution of the formation.

An early stage of recrystallization of micrite of the lower member occurred before deposition of intraclastic fragmental rocks of the middle member. Providing the temperature was 100°C or less, the isotopic ratios of microsparite indicate oxygen exchange of an initial marine calcite with fresh water. There is surely no indication by grain size of the products microsparite and sparite that the temperature of such recrystallization was elevated significantly. Thus, I interpret the early recrystallization of the micrite to have been a fresh-water diagenesis that occurred in the micrite after it was exposed, either tectonically or eustatically. Erosion of the lower member to provide clasts for the middle member surely required the lower member to have been raised above wave base. It is thus reasonable to ally exposure and lithification of the carbonate mud by fresh-water diagenesis as concomitant events.

Carbonate rocks in the lower and middle members have locally undergone more intensive recrystallization due to hydrothermal fluids. Isotopic evidence suggests (Speed and Clayton, 1973) that the temperature of such recrystallization was $\geq 200°C$. The meta-limestones of the hydrothermal phase are most abundant in the middle member and at the stratigraphic top of the lower member. The distribution suggests fluid transport through zones in or above the middle member and local penetration stratigraphically downward into the lower member. Such flow paths are entirely reasonable because of the large permeability contrast that probably existed between the lower and middle members.

Where the hydrothermal phase is most intensive in the middle and lower members, extensive solution breccia occurs in the upper member. The relation suggests that dissolution of sulfate and recrystallization of some adjacent carbonate rocks were concomitant. Further, if it is correct that calcitization of gypsum was continuous with dissolution of gypsum, calcitization was thus penecontemporaneous with the later recrystallization of the carbonate rocks.

The hydrothermal recrystallization of the limestones and calcitization and solution in the upper member are clearly postdepositional and occurred apparently during or after folds of set 1 and nappe transport. Such events thus are epigenetic.

Summary and Sequence of Events

Deposition of fine-grainted silicate sediments together with less abundant carbonate occurred with lateral uniformity in shallow seas of the Carson region during the Early Jurassic, from the systemic boundary to early Toarcian or later. Between early Toarcian and Bathonian time, the influx of silicate mud and silt ceased at the site in which the Lovelock Formation was to be deposited, and deposition of carbonate mud and sparse terrigenous sand followed conformably in a probably euxinic environment. Thus, the changes recorded by the deposition of sediments of the lower member of the Lovelock Formation are principally the effacement of the silicate mud source or bypassing of the silicate mud influx.

Succeeding events involving the Lovelock Formation up to the deformation forming fold set 2 are also in the interval, early Toarcian-Bathonian. The next event after micrite deposition was subaerial exposure and fresh-water diagenesis followed by fluvial or littoral erosion. Competent intraclasts derived from the lithified micrite were laid down in close proximity to their source as the gravels of the conglomerate of the middle member. Succeeding deposits of the calc-breccia are accumulations of particles from a number of subenvironments of the littoral zone. These deposits ostensibly represent significantly greater lateral transport and mixing than do those of the calc-conglomerate and deposition in a lower flow regime. Progressive erosion wore down the pebble sources, smoothed the terrain, lengthened particle transport paths, and provided a general change to a low-relief carbonate bank environment. The excellent mixing and stratification of the diverse particles of the calc-breccia indicate, however, that circulation and turbulence of marine waters on the bank were significant. A possible mudflow of silicate, intraclastic, and extraclastic detritus is envisaged as entering the littoral zone, implying nearby inland relief of at least modest degree.

Deposition of 100 m or more of sulfate and calcarenite followed conformably above the calc-breccia. The sulfate rocks formed at least in part by direct precipitation from standing water, implying growth of a barred basin. Onset of sulfate deposition was synchronous with local effacement of the earlier carbonate bank environment, due either to deepening or landward transgression of the bank environment represented by the middle member.

The nature and sequence of events associated with cessation of deposition of the Lovelock Formation are not certain. One possibility is uplift and marine withdrawal, then folding and nappe transport. Another possibility is that folding was actually commensurate with deposition of the middle and upper members; that is, they were deposited in a synclinal trough. Increased deformation, nappe motion, and perhaps, regional uplift finally obliterated the marine basin.

The Lovelock Formation in the gypsum nappes was folded recumbently before or during nappe emplacement. Calcitization of sulfate occurred at places, chiefly where sulfate was at the base of the nappe. Thus, calcitization is probably postrecumbent folding. Dissolution of sulfate, formation of solution breccia by compaction and, sparsely, by collapse, and intensive hydrothermal recrystallization of limestones were postrecumbent-folding events in the Lovelock Formation that were possibly penecontemporaneous with calcitization.

The piling-up of nappes was completed by about 163 m.y. ago, approximately Bathonian or earlier time. Structural relations suggest that the nappes were emplaced in a major syncline which continued to fold on a northerly axial trace and then, to be refolded on an easterly axial trace.

Tectonism during Deposition

The occurrence of tectonism as manifested by folds and nappes in the Carson region and the deposition of the Lovelock Formation were closely spaced in time, in the Toarcian-Bathonian interval. The Lovelock Formation apparently contains the youngest deposits in the Mesozoic succession in the area, and its sediments represent an abrupt lithic change from the relatively uniform subjacent Jurassic pelite. The question thus arises whether the deposition of all or part of the Lovelock Formation records the onset of tectonism, such that deposition was syntectonic. The alternative is that the Lovelock Formation is pretectonic, and its lithic succession is owing only to lateral motion of depositional regimes, perhaps coupled with eustatic sea-level changes.

Each lithic subunit of the Lovelock Formation could have formed in a tectonically stable littoral-neritic complex. The lower member could have been lagoonal, provided that the silicate influx was low. The conglomerate may represent beach gravel eroded and deposited during rapid lowering of sea level. The breccia is an accumulation of allochthonous particles from shallow bank environments. The evaporite-calcarenite sequence was perhaps deposited in a marginal basin during a sea-level rise in which the basin barrier grew vertically at just the right rate to adjust the normal marine inflow for gypsum saturation within the basin.

In their vertical succession, however, the subunits of the Lovelock Formation cannot have been produced solely by laterally propagating environments as is occurring, for example, in the Persian Gulf (Kinsman, 1969). Oscillation in water depth with time seems required by the following observations:

1. The basal micrite was deposited in a euxinic environment; it was then uplifted as indicated by probable fresh-water diagenesis and certainly by its wave and (or) fluvial erosion.

2. The existence in the middle member of skeletal-oöpelletal-intraclastic calc-breccia above calc-conglomerate indicates significant mixing of particles from a variety of marine subenvironments over wave or fluvial gravels, hence probable slight submergence.

3. The accumulation of perhaps 100 m of evaporite and associated carbonate of the upper member over clearly littoral deposits of the middle member indicates subsidence of at least 100 m between the terrestrial shoreline and the evaporite basin barrier. The subsidence indicated here was likely coupled to the submergence noted above.

Each of the bottom motions could have been eustatic or tectonic. For example, sudden rise in sea level after deposition of calc-breccia, coupled with construction of a barrier bar at the former bank margin, could in principle have produced the barred evaporite basin. The distinction between eustatic and tectonic changes of sea level is clearly difficult because the small lateral exposure of the Lovelock Formation precludes analysis of its lateral differentiation. More broadly, however, the demonstrable temporal proximity of deposition of the Lovelock Formation and folding and nappe emplacement surely favor tectonic effects and acceptance of the proposition that the Lovelock Formation is syntectonic. The corollary is that the sequence of paleoenvironments indicated by the Lovelock Formation represents the transition in surface conditions from initial open marine silicate deposition to that of an emergent tectonically active terrain.

STRATIGRAPHIC CORRELATIONS

Within the northern Carson Sink region (north of 48° N.), the Lovelock Formation appears to be the only vestige of originally widespread gypsum-carbonate deposits that are now represented by bodies of carbonate breccia and marble, the rauhwackes (Speed, 1974). Thirty km south of Gypsum Mountain in the Mopung Hills at the southern tip of the West Humboldt Range, however, a nappe contains an undated assembly of gypsum, calcarenite, dark micrite, breccia, and quartz arenite. The strong lithic resemblance of the Mopung Hills rocks and those of the Lovelock Formation and their similar associations with Jurassic pelite are sufficient to indicate probable correlation. As in the case of the Lovelock Formation, the Mopung Hills rocks can also be interpreted to be an isolated remnant of evaporite deposits that escaped complete conversion to rauhwacke. It should be noted that the Mopung Hills deposits contain significant volumes of quartz arenite, whereas discrete quartz sandstone deposits are rare in the Lovelock Formation.

In the Dixie Valley region east of the Carson Sink, Speed and Jones (1969) found that syntectonic quartz arenite of the Boyer Ranch Formation was deposited in the same duration that is here given for the Lovelock Formation. Later studies indicate that the westernmost Boyer Ranch Formation in the Stillwater Range (Speed, 1974) contains rauhwacke such that it is inferred that gypsum-carbonate units originally existed in the Boyer Ranch Formation. The lithic and temporal relations allow correlation of the Lovelock and Boyer Ranch Formations. The existence of gypsum-quartz arenite-limestone in the Mopung Hills clearly supports the contemporaneity of evaporite and quartz sand deposition in the Carson region in Jurassic time. The paleogeographic evolution as it relates to Middle Jurassic tectonism will be expanded in another paper.

A large undated deposit of gypsum occurs with carbonate rocks in the vicinity of Gerlach, Nevada, 80 km northwest of Gypsum Mountain (Fig. 1). Layered rocks that crop out in the intervening distance are Triassic and Jurassic pelites (Tatlock, 1966) which are similar to those of the Carson region. Because evaporite deposits are unknown in the pelites, it is reasonable to suggest that the Gerlach sulfate deposits are correlatives of the Lovelock Formation or, more generally, that they are postpelite. If such long-range correlations are correct, evaporite deposits of Toarcian-Bathonian age may have extended over a large terrain west of the Carson Sink. Judging from the history of the Lovelock Formation, evaporite deposition seems more likely in a series of tectonically barred basins than in a single continuous sea.

ACKNOWLEDGMENTS

L. L. Sloss read this paper and has provided valuable counsel in all aspects of the study. I am grateful to Lee C. Gerhard of the West Indies Laboratory of Fairleigh-Dickinson University, who examined thick sections of microbreccia for their content of biogenic, notably algal, components. Robert N. Clayton of the University of Chicago kindly provided the isotopic analyses. This study was under the support of National Science Foundation Grant GA–1574.

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MANUSCRIPT RECEIVED BY THE SOCIETY FEBRUARY 22, 1973
REVISED MANUSCRIPT RECEIVED JULY 21, 1973

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Stratigraphy and Depositional History of the Star Peak Group (Triassic), Northwestern Nevada

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Grants GA 1398 (1
1974) to Stanford
supported by a Te
We thank A. K.
and D. H. Whiteb

Abstract

The Star Peak Group in and near the Sonoma Range one-degree quadrangle, northwestern Nevada, is redefined to include the mainly calcareous strata that overlie the predominantly volcanic rocks of the Koipato Group and in turn are overlain by the terrigenous clastic rocks of the Auld Lang Syne Group. The Star Peak Group ranges in age from late Spathian (latest Early Triassic) to late Karnian (middle Late Triassic), and it is as much as 1,200 m thick. Although the paleogeography of the group has been affected locally by post-Triassic low-angle faulting, widespread formational units within the Star Peak genetically relate all parts of its outcrop region and obviate the need to separate these rocks into different major structural blocks, as has been done in the past.

In the older parts of the Star Peak Group, complex stratigraphic patterns among a variety of carbonate and terrigenous clastic rocks resulted from localized relative uplift, first early and then late in Middle Triassic time. Widespread diagenetic secondary dolomitization of calcareous rocks in the older part of the section further complicates the primary stratigraphic patterns. Following the earlier of these intra-Star Peak tectonic episodes, regionally uniform calcareous rocks of late Anisian age blanketed most of the outcrop area. These rocks contain a rich pelagic fauna and were evidently deposited below wave base. The more western of these rocks grade upward into dark cherty limestone which was deposited in basinal and slope environments concomitantly with uplift and erosion, during Ladinian time, in the central part of the Star Peak outcrop area. South and southeast of the uplifted area, subsidence and peritidal deposition took place followed by deposition of supratidal algal-laminate dolomite. This dolomite was deposited across the beveled uplift and correlates with platform-margin and basinal limestone farther west. Thereafter, lower Karnian platform limestone thickly blanketed the outcrop area and built regressively westward out over the basinal deposits. Following a widespread mid-Karnian break in deposition, local erosion, and deposition of terrigenous clastic rocks, platform carbonate rocks again blanketed the outcrop area during late Karnian time and extended an unknown distance westward, perhaps as far as the original site of the Sierran–eastern Klamath belt.

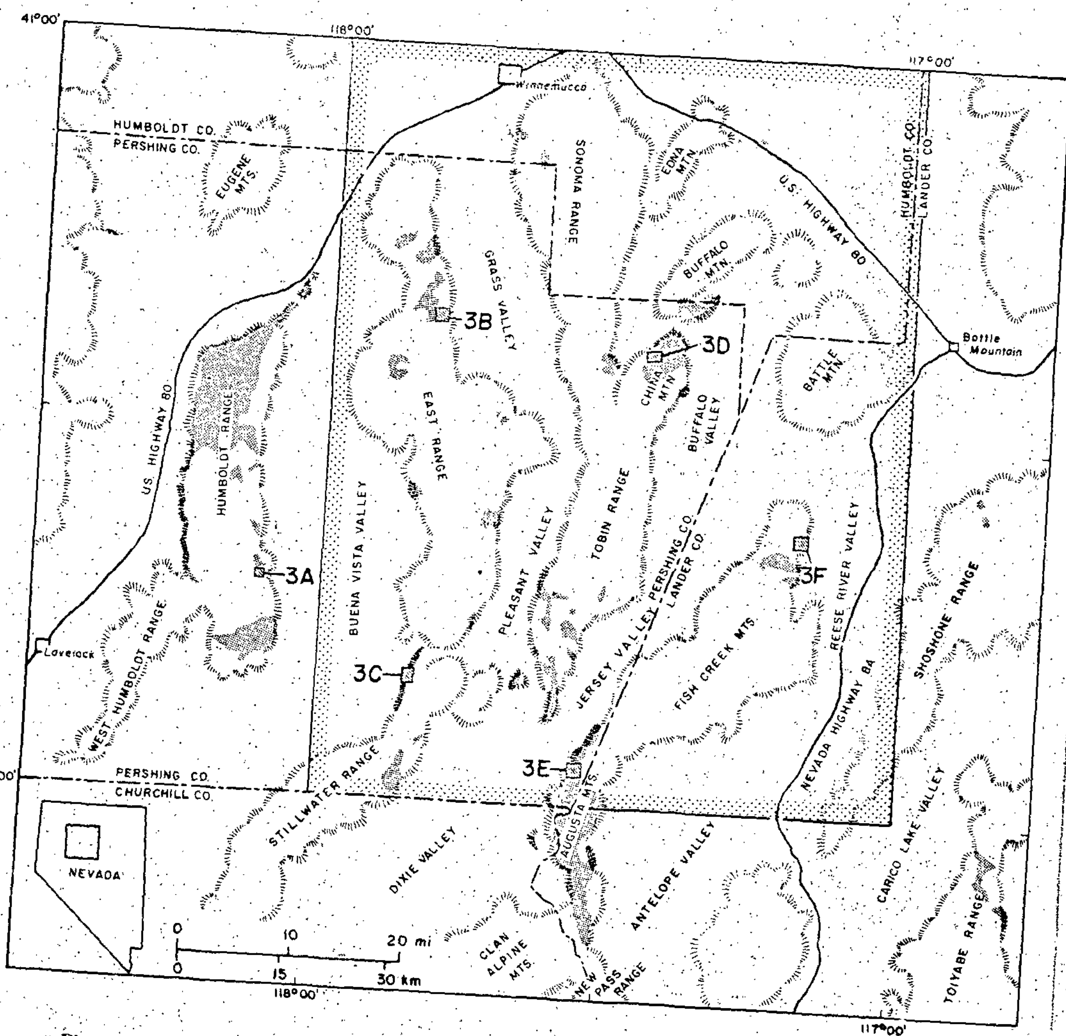

Figure 1. Index map showing location of Star Peak Group exposures (heavy stipple) in and near the Sonoma Range one-degree quadrangle (outlined by lightly stippled border). Location of maps shown in Figure 3 are indicated by labeled rectangles.

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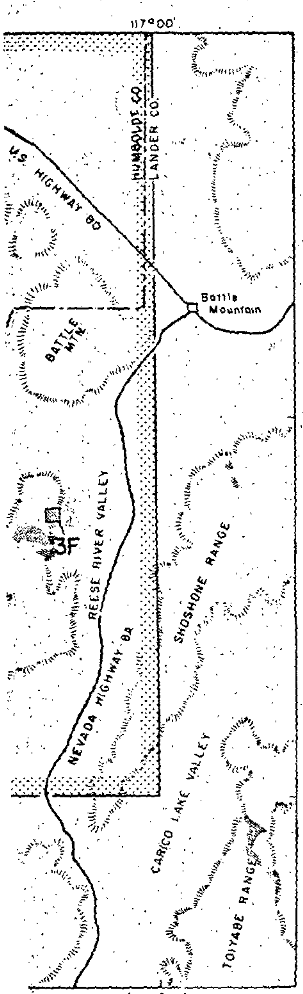

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Introduction

The Star Peak Group is a distinct natural grouping of largely marine calcareous strata that range from Early to middle Late Triassic age and that occur in scattered exposures within an area exceeding 5,000 km^2 in northwestern Nevada (Fig. 1). Where the group is completely preserved, it attains thicknesses exceeding 1,000 m. The genetically coherent carbonate platform complex represented by the Star Peak Group contrasts sharply with the overlying Auld Lang Syne Group which consists of metapelitic rocks and sandstone. The Star Peak also contrasts with the unconformably underlying Koipato Group, which is composed of volcanic and clastic sedimentary rocks.

The Star Peak Group was first recognized as a major natural subdivision among the pre-Tertiary strata of northern Nevada more than 100 years ago during the initial exploration of this region by the 40th Parallel Survey under the direction of Clarence King. Since then, much knowledge about the depositional and tectonic history of the Star Peak Group has accumulated. The main obstacles to a coherent regional depositional synthesis of these rocks have been their discontinuous outcrops, difficulty in ascertaining the extent to which they have been rearranged by thrust faulting, and misinterpretation of massive secondary dolomite units in the lower part of the section.

All of the major components of the Star Peak Group are explicable in terms of a complicated pattern of carbonate deposition and diagenesis and contemporaneous tectonism. The regional synthesis presented in this paper describes an unusually compact example of lateral and vertical interrelations representing depositional environments that range from supratidal to below wave base (Fig. 2). Geologic maps of the Star Peak Group exposures that are significant for stratigraphic nomenclature and correlation are shown in Figure 3; a fence diagram illustrating the stratigraphic relations among these and other exposures of the group is shown in Figure 4. The Triassic carbonate units consist of diverse rock types that are best understood in terms of the environments in which they were deposited. Accordingly, a new scheme of stratigraphic nomenclature is proposed herein based on revision and documentation of the ages, correlations, and stratigraphic relations of the Star Peak components (Fig. 5).

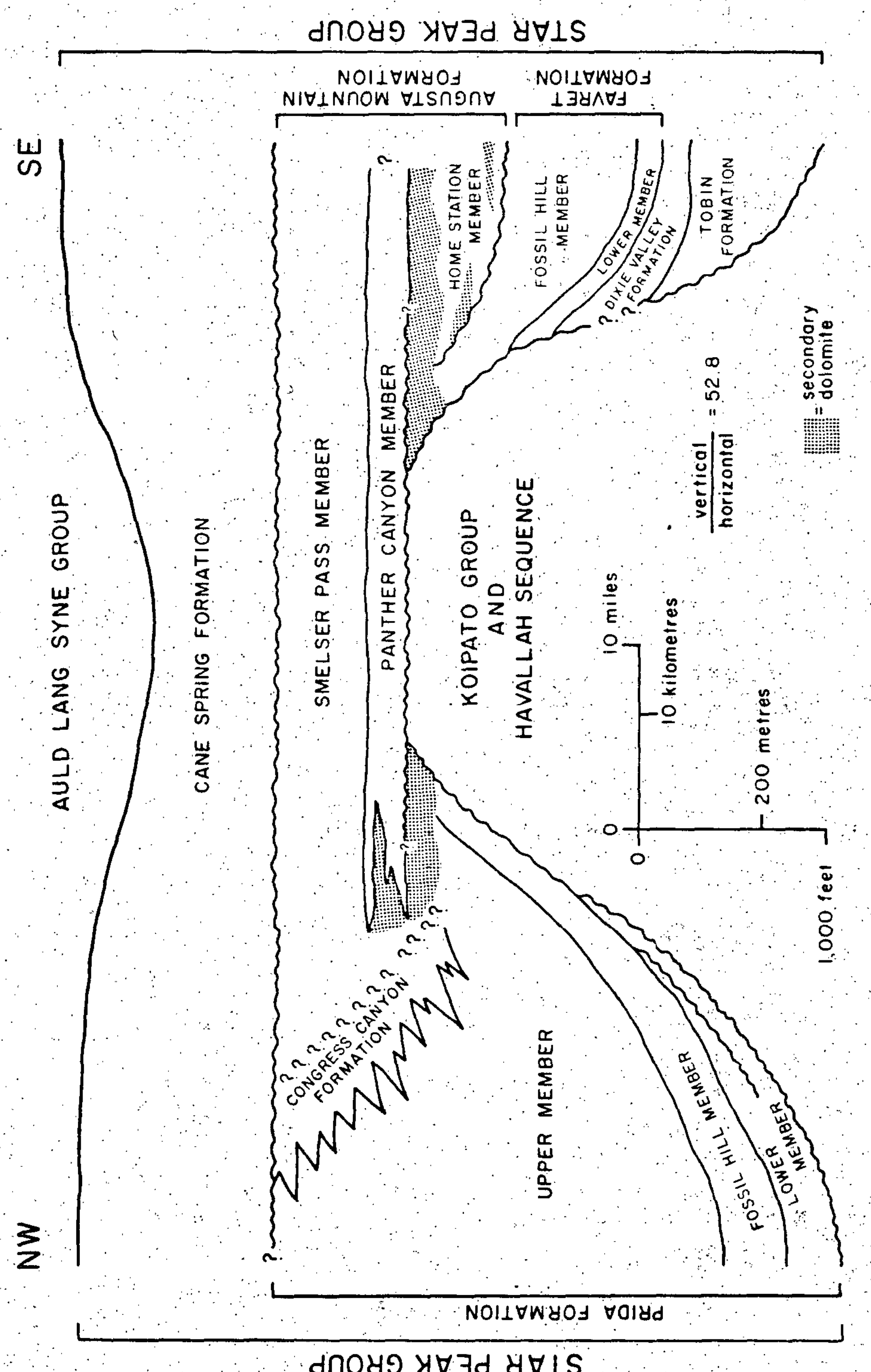

Figure 2. Diagrammatic cross section of the Star Peak Group trending southeasterly from the northern Humboldt Range through the southern Tobin Range to the Augusta Mountains.

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Although the correlations, stratigraphic relations, and rank of previously named formations of the Star Peak Group have been revised, their lithologic boundaries have not been changed from those embodied in their original descriptions. Our revision has entailed incorporating some previously named units into others and dropping one name, the "Natchez Pass Formation."

REGIONAL GEOLOGIC SETTING

As first described by King (1878), typical exposures of the Star Peak Group are found in the vicinity of Star Peak in the Humboldt Range, where they were subsequently shown to be repeated structurally and to include fault blocks of the stratigraphically underlying Koipato Group. Nonetheless, the name "Star Peak" was correctly applied, in part, by King (1878) to isolated exposures of Triassic carbonate rocks elsewhere in the Humboldt Range and nearby ranges to the east. Subsequent study of the northern Humboldt Range by Cameron (1939) contributed to understanding the typical Star Peak section. This and work on the comparable Triassic rocks in the ranges to the east by Ferguson and others (1951a) enabled Silberling and Wallace (1967, 1969) to piece together the stratigraphic section of the type Star Peak.

For strata that are now regarded as parts of the Star Peak Group in the Sonoma Range one-degree quadrangle (Fig. 1), Muller and others (1951; see also Ferguson and others, 1951a, 1951b, 1952) established many new formations in order to express both lateral variation and the differences between sections that were interpreted as having been juxtaposed by tens of kilometres of displacement on the inferred "Tobin thrust" (Muller, 1949). So as not to prejudge the magnitude of this inferred thrust, Muller's supposed "Upper Plate (eastern) facies" and "Lower Plate (western) facies" of Triassic rocks in the Sonoma Range quadrangle were informally designated, respectively, as the "Augusta sequence" and "Winnemucca sequence" by Silberling and Roberts (1962).

Detailed work by Burke (1970b, 1973) in the southern Tobin Range, through which the typical trace of the "Tobin thrust" was supposed to extend, demonstrates that no such thrust fault exists and that the differences between the "Winnemucca" and "Augusta" sequences can be explained for the most part by rapid facies changes. Moreover, other recent findings regarding the character and age of thrust faulting in north-central Nevada (Silberling, 1970, 1973; MacMillan, 1971, 1972; Nichols, 1971; and Speed, 1971a, 1971b) indicate that the Star Peak Group rocks were not drastically rearranged by regional thrusting. The Golconda thrust, which does juxtapose entirely different upper Paleozoic facies in this region and was regarded originally as the same structure as the "Tobin thrust," evidently predates

Figure 2. Diagrammatic cross section of the Star Peak Group trending southeasterly from the northern Humboldt Range through the southern Tobin Range to the Augusta Mountains.

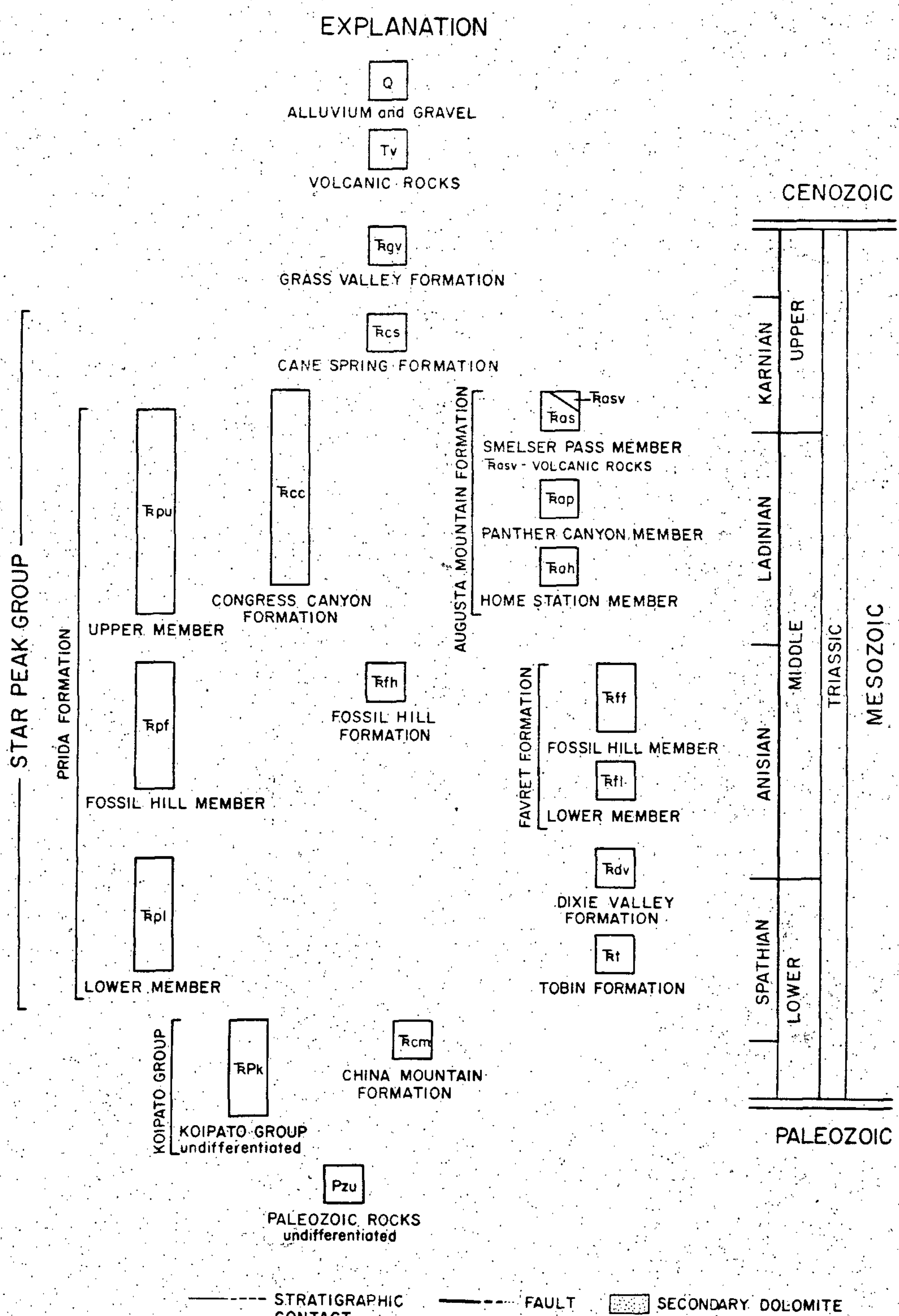
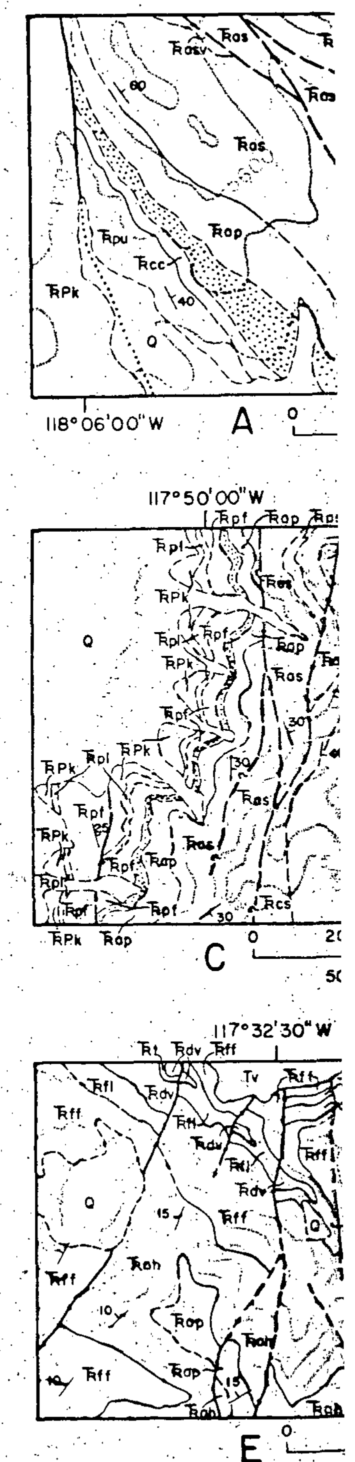


Figure 3 (facing pages). Geologic maps of selected exposures of the Star Peak Group in A, southern Humboldt Range; B, northern East Range; C, northern Stillwater Range; D, western



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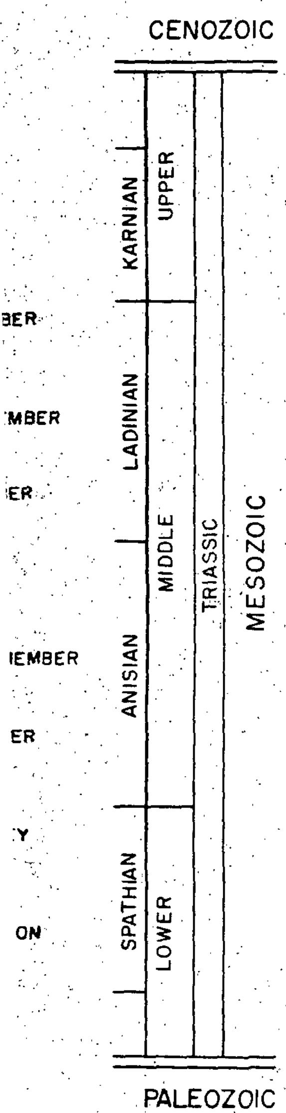

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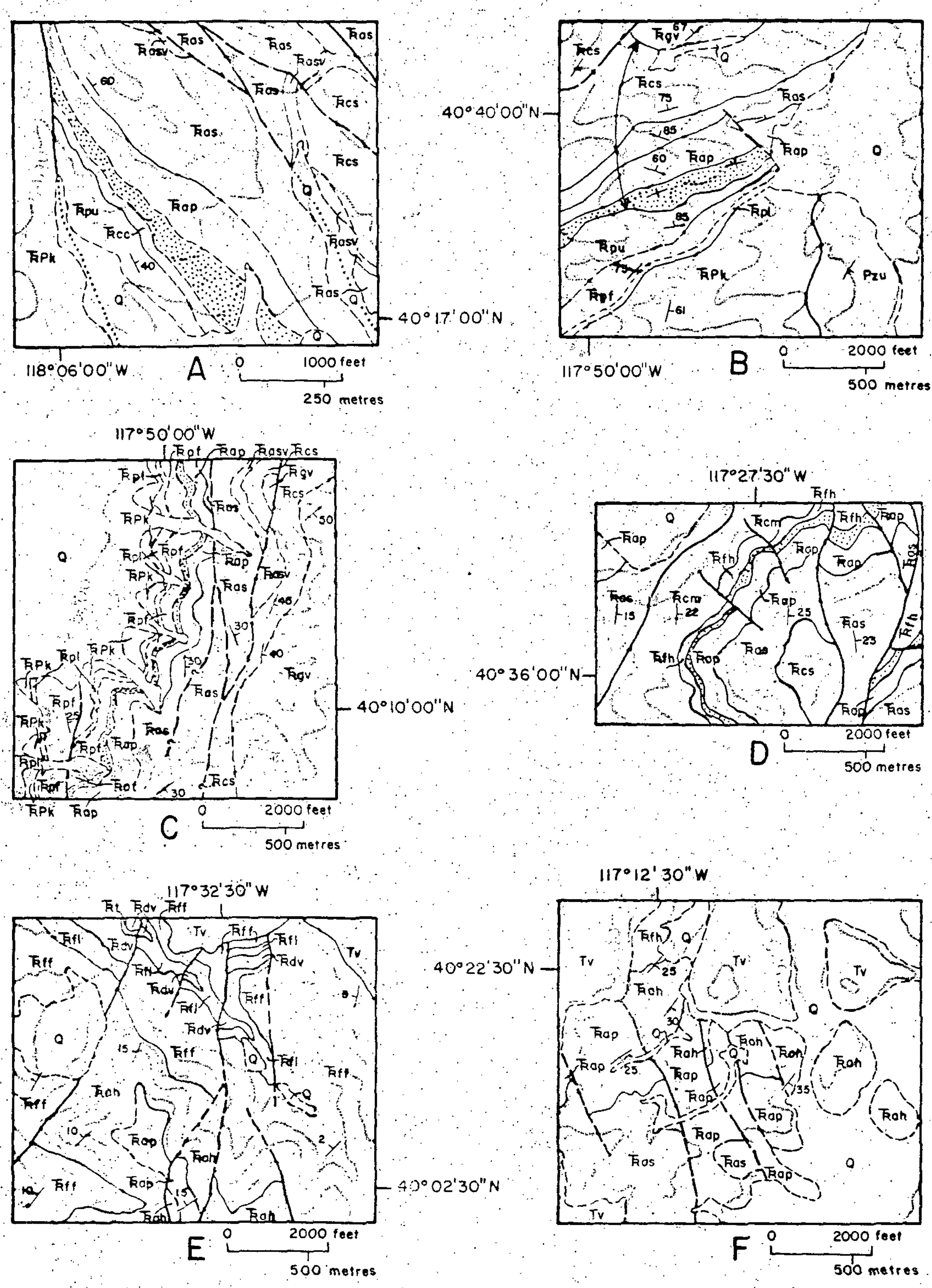

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China Mountain; E, northern Augusta Mountains; F, northern Fish Creek Mountains. See Figure 1 for locations. Arrow on map B delineates rocks included in the "Natchez Pass Formation" of Ferguson and others (1951a).

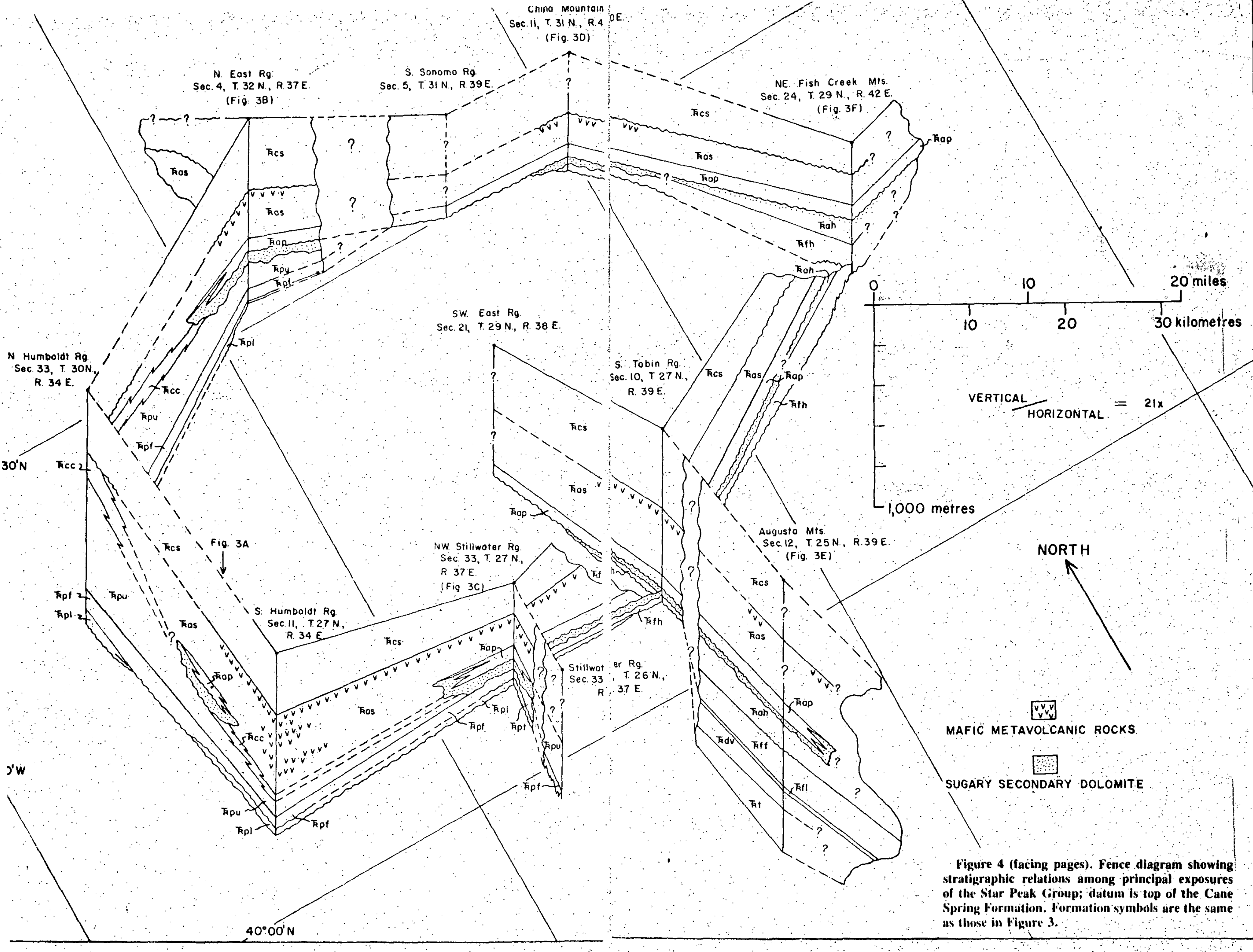

Figure 4 (facing pages). Fence diagram showing stratigraphic relations among principal exposures of the Star Peak Group; datum is top of the Cane Spring Formation. Formation symbols are the same as those in Figure 3.

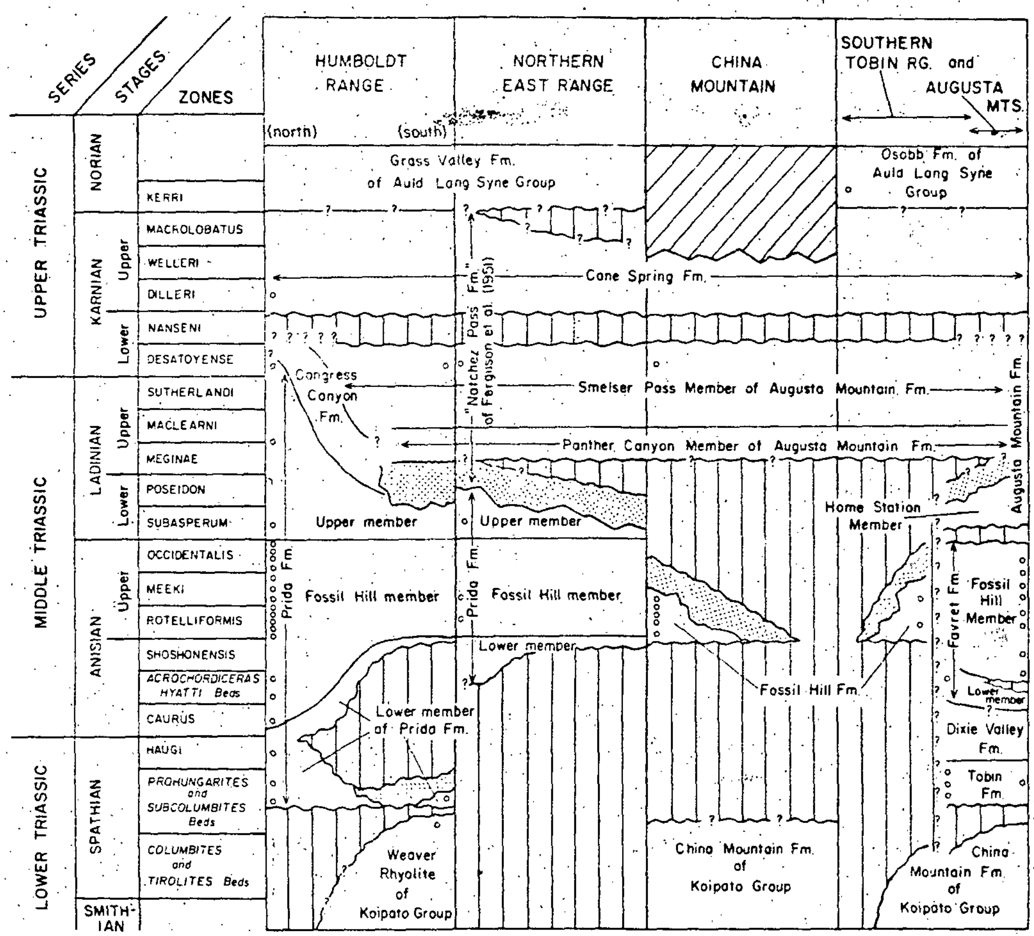

Figure 5. Time-stratigraphic correlation chart of the Star Peak Group at localities significant for stratigraphic nomenclature. Small circles represent occurrences of age-diagnostic fossils; stippled pattern indicates secondary dolomite; vertical ruling indicates stratigraphic hiatus, and diagonal ruling indicates lack of data.

deposition of the Star Peak Group, part of which overlaps the Golconda thrust (Nichols, 1971; Silberling, 1973, 1975). Displacement on the Golconda thrust in north-central Nevada most likely took place during the Sonoma orogeny in latest Permian or Early Triassic time. Therefore, lateral changes in Triassic rocks deposited subsequent to the Sonoma orogeny must be explicable without calling upon large-scale tectonic rearrangement, and separation of the Triassic strata into the tectonically delimited "Winnemucca" and "Augusta" sequences is no longer useful. Instead, these rocks lend themselves to treatment as a single lithologic entity whose internal

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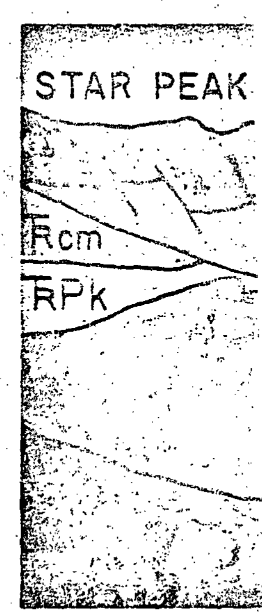

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variations (see Fig. 4) reflect a coherent, albeit complex, pattern of sedimentary environments. The lateral relationships do indicate, however, the possibility of some tectonic telescoping of facies on low-angle faults within the Star Peak Group, particularly in the three places in the fence diagram indicated by gaps across which lithologic correlations are questioned. These localities are in the northern Stillwater Range, southern Tobin Range, and between the East and Sonoma Ranges.

The Star Peak Group either rests unconformably on rocks of the predominantly volcanic Koipato Group (Fig. 2) which overlaps the Sonoma orogenic belt or, where the Koipato was removed by erosion, the Star Peak rests directly on the deformed Lower Permian and older(?) rocks of the Golconda allochthon. Deformation during the Sonoma orogeny is well shown at the south end of China Mountain (Fig. 6). Here the Hoffman Canyon thrust separates two parts of the intensely deformed Golconda allochthon having contrasting tectonic fabrics, and the thrust is overlapped by the nearly flat-lying tuffaceous rocks of the Koipato Group (Nichols, 1972). The Star Peak carbonate rocks in turn overlie the Koipato.

All of the known exposures of the Star Peak Group and closely related

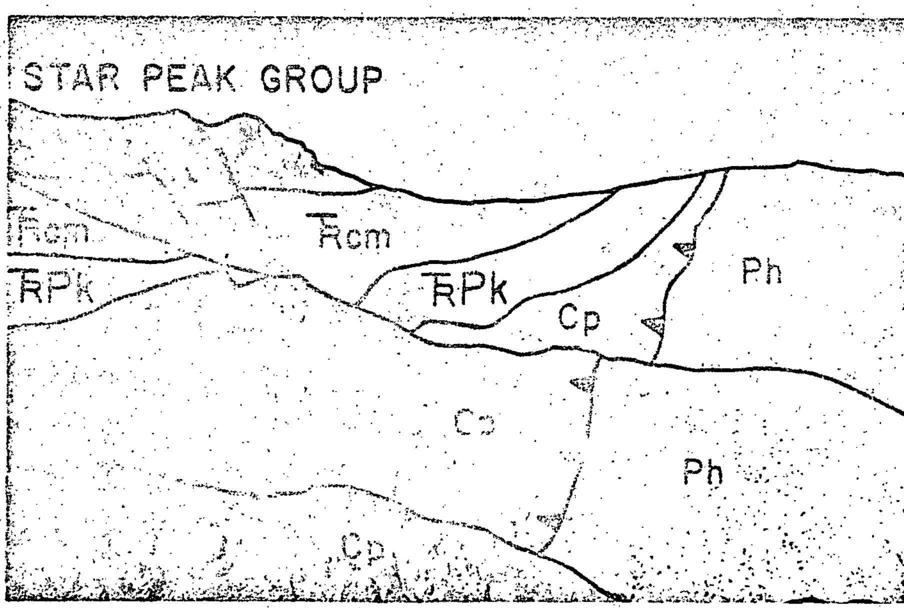

Figure 6. View eastward across Hoffman Canyon at China Mountain showing trace of the Hoffman Canyon Thrust, the Koipato Group, and part of the Star Peak Group. Rock-unit symbols correspond to those in Figure 3, except for the Golconda allochthon wherein Ph denotes the "Havallah Formation" and Cp the "Pumpernickel Formation," both after Ferguson and others (1952). Photo by S. W. Muller, about 1935.

strata are confined to the Humboldt Range and the ranges within the Sonoma Range quadrangle, except for isolated outcrops in the New Pass, Toiyabe, and Shoshone Ranges. Rocks belonging to the group have so far received only limited description in the form of map explanations, student theses, and a few geographically restricted studies. These rocks had not previously been considered as a genetically coherent group having wide regional extent. Some attempt at interpreting the regional depositional framework of the Star Peak Group in the Humboldt Range was made by Silberling and Wallace (1969) who recognized in the type Star Peak exposures the same formational units that were defined by Ferguson and others (1951a) in the East Range, the next range to the east. Geographically restricted research by Burke (1973) in the southern Tobin Range, by Nichols (1972, 1974) at China Mountain, and by the Stanford Geological Survey summer field camps in the Augusta Mountains during 1970 and in the northern East Range during 1971 improved knowledge of the distribution and correlation of previously recognized subdivisions within the group in the vicinity of the Sonoma Range quadrangle. Farther east, near Hall Creek in the northern Toiyabe Range, Stewart and McKee (1977) discovered a large exposure of Triassic carbonate and clastic rocks that resemble part of the Star Peak Group. Rocks exposed in small areas in the northern Shoshone Range were compared by Gilluly and Gates (1965) with the China Mountain Formation but are now recognized as part of the Star Peak (Nichols, 1971). In the New Pass Range, south of the Sonoma Range quadrangle, Triassic rocks resembling those of the Star Peak Group have been studied by MacMillan (1972) and Willden and Speed (1974).

A major obstacle to an understanding of the Star Peak Group has been the massive bodies of saccharoidal dolomite, locally forming much of the lower part of the section, which have been misinterpreted as primary stratigraphic units. The secondary and nonstratigraphic character of these dolomite bodies has been demonstrated by Nichols (1974) who found that they relate spatially to an overlying unit, the Panther Canyon Member of the Augusta Mountain Formation (Fig. 2). The Panther Canyon is a fine-grained, laminated, stromatolitic dolomite which evidently formed in a sabkha-flat environment. This distinctive unit appears in all exposures of the Star Peak Group, except those in parts of the Humboldt and Stillwater Ranges, and is coextensive with the underlying secondarily dolomitized rocks.

Hydrothermal alteration of the carbonate rocks of the Star Peak Group, especially in the more northwestern outcrops, seriously hampers petrographic interpretation of depositional and diagenetic fabrics. Such alteration is not surprising, because these exposures occur along the eastern edge of the batholithic region in northwestern Nevada, interpreted by Smith and others (1971) as connecting the Sierra Nevada and Idaho Batholiths.

Depositional History

The depositional history of the Star Peak Group is complicated by coeval tectonic activity within the site of sedimentation. As the lithologic nature of platform carbonate rocks, such as those of the Star Peak, is especially sensitive to relative changes in sea level, episodes of tectonism during Star Peak deposition resulted in striking facies changes different from those that would develop by continuous deposition in a generally subsiding marine basin. Although the geologic events recorded in the Star Peak rocks characterize only a relatively small area, they provide information on the nature of the continental margin during a critical time of apparent change in tectonic style at this general latitude in western North America. Prior to deposition of the Star Peak Group, the tectonic record of much of Paleozoic and earliest Triassic time has been characterized as one of developing and collapsing marginal (or "inner arc") ocean basins (Burchfiel and Davis, 1972; Churkin, 1974; Silberling, 1973), whereas during or after Star Peak time, the Sierra Nevada magmatic arc became established at the edge of an "Andean-type" continental margin (Schweickert and Cowan, 1975). The actual record of tectonic events during the middle part of Triassic time is meager even though some first-order structural events have been postulated for that time, such as truncation of the continental margin (Burchfiel and Davis, 1972) and large-scale strike-slip rifting (Jones and others, 1972; Silver and Anderson, 1974).

The depositional and tectonic history of the oldest parts of the Star Peak Group have been obscured by subsequent intra-Star Peak uplift, erosion, and secondary dolomitization. During late Spathian time, open-marine calcareous strata may have been deposited upon a fairly flat surface throughout much of the western and southern part of the Star Peak outcrop area, as if the entire region were abruptly inundated by the sea. However, only remnants of such strata are preserved in the lower member of the Prida Formation and in the Tobin Formation. Stratigraphic evidence such as that in the Humboldt Range (Fig. 22) indicates that local relative uplift and erosion took place during early Anisian time, although the nature of the uplift—whether by faulting or folding—is not clear. Farther to the southeast, the coarse clastics in the Dixie Valley Formation were evidently shed southward from a highland within the Star Peak area, also documenting relative uplift during the early Anisian. Too little of the record is preserved, however, to determine the shape and size of the area or areas that underwent relative uplift at that time.

Deposition of the basinal marine calcareous deposits of the Fossil Hill Member of either the Prida or Favret Formations began during middle Anisian time in subsided parts of the Star Peak area, and by late Anisian time Fossil Hill rocks blanketed the entire region. These deposits overlapped the previously uplifted areas as if the entire region had again undergone relative subsidence. The known and inferred distribution of the Fossil Hill is shown in Figure 31; platform or nearshore carbonate equivalents of these basinal rocks are unknown.

Although the older parts of the Star Peak Group are mainly calcareous rocks, the first record of carbonate-platform construction is found in rocks of early Ladinian age. Figures 31B through 31F diagrammatically show

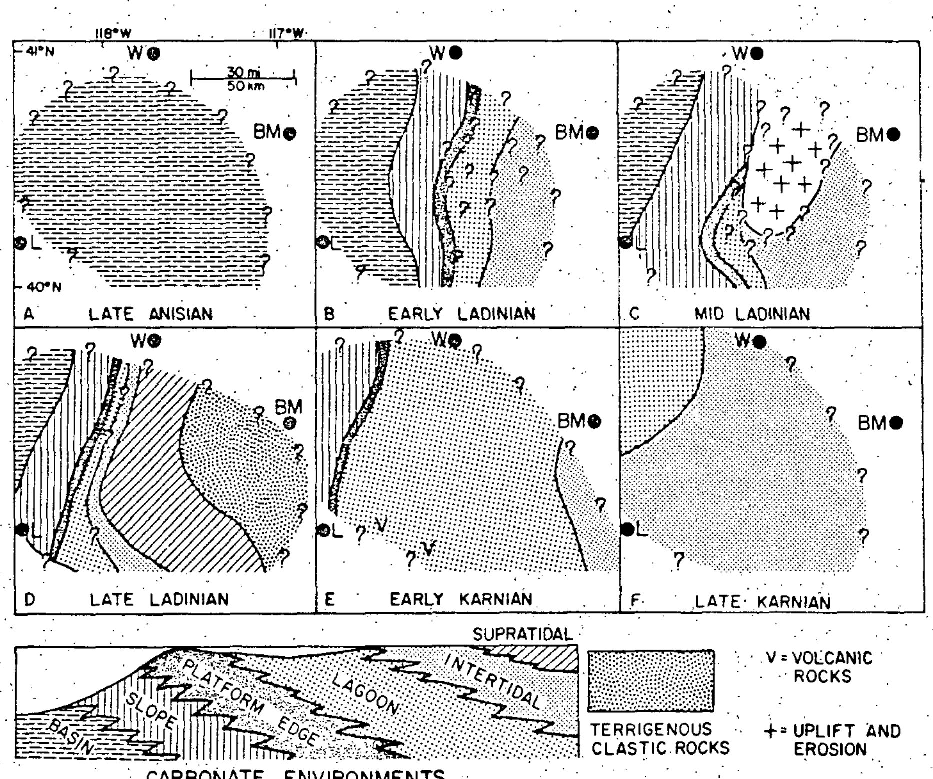

Figure 31. Paleogeographic maps of the Star Peak Group at different times during its deposition. See Figure 5 for series assignment of Triassic stages. Area of maps is approximatley that in Figure 1; L, Lovelock; W, Winnemucca; BM, Battle Mountain. The map patterns correspond to those on the conventional model of near-shore carbonate environments shown beneath the maps.

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In the western Star Peak region, open-marine Anisian strata of the Fossil Hill Member grade upward into dark, laminated, cherty limestone of the upper member of the Prida Formation. This progression represents a continuation of basinal deposition during Ladinian time concomitant with uplift and erosion farther east in the central part of the present Star Peak outcrop area (Figs. 31B, 31C). Existence of a slope environment between the basin and platform is shown by sedimentary breccia and soft-sediment deformation within the upper Prida section. South and east of the uplifted area, subsidence and peritidal deposition of the carbonate and clastic rocks of the Home Station Member of the Augusta Mountain Formation took place. A topographic break must have separated the upper Prida basinal deposits from those of the Home Station, but its nature is obscured by erosion of the uplifted area and associated secondary dolomitization, as indicated by the liberal use of question marks on the reconstructed paleogeogrpahy shown in Figure 31C. Little actual record is preserved of the lower or middle Ladinian platform margin whose position evidently was tectonically controlled because it coincides with the western edge of the uplifted area. Although erosion during Star Peak time exposed pre-Star Peak rocks on the uplifted platform, coarse-grained terrigenous clastic material was not shed westward into the basinal upper Prida deposits. Siliceous sand, grit, and pebbles are sporadically scattered through the correlative Home Station Member carbonate rocks and may have been derived from the platform which therefore may have been an eastwardly tilted block. This geometry is also suggested by progressively deeper erosion of Fossil Hill strata beneath the Ladinian unconformity in a westerly and northwesterly direction at China Mountain and in the southern Tobin Range, respectively. However, the nature of the uplift, whether by faulting or folding, is unknown.

By late Ladinian time the uplifted area was beveled by erosion, and the entire eastern and central Star Peak regions became a vast supratidal flat upon which the Panther Canyon Member of the Augusta Mountain Formation accumulated under evaporitic conditions. First the algal-laminate "primary" dolomite of the Panther Canyon formed, and then, more locally, the Panther Canyon clastic sediments spread over part of the carbonate platform from the northeast. Regionally extensive secondary dolomitization of older Star Peak limestone took place just prior to or during Panther Canyon deposition (Nichols, 1972, 1974). Supratidal conditions alternated with more open-platform intertidal or lagoonal environments along the west and southwest side of the platform. This was manifiest by intertongues in the Panther Canyon of coarse-grained secondary dolomite in the northern East Range and in the Stillwater Range. The position of the platform margin is fairly well located geographically for this time (Fig. 31D), and actual platform margin deposits crop out in the southern Humboldt Range. In the northern part of the Star Peak area, the narrowness of the belt in which the more outer-platform deposits of this age occur may result in part from telescoping of facies by low-angle post-Triassic faults such as those of the Clear Creek system of thrust faults (Silberling, 1975) which have displacements of as much as a few tens of kilometres.

Further subsidence during the early Karnian allowed the platform limestone of the Smelser Pass Member of the Augusta Mountain Formation to thickly blanket the region. At the same time the platform margin, represented by the Congress Canyon Formation, built regressively westward out over the persistent basinal deposits of the upper member of the Prida Formation (Fig. 31E). A paleogeographic complication during this time is the prevalence of mafic volcanic rocks in the Smelser Pass Member in the southern Humboldt and Stillwater Ranges. In that part of the region the Star Peak platform may have been supported by a local volcanic center (Silberling and Wallace, 1969, p. 30). Unfortunately, no exposures of Star Peak rocks exist farther west or south, so the paleogeographic setting of these volcanic rocks cannot be fully known. The margin of the platform presumably swung around this volcanic center to the west and south, because basinal deposits correlative with the Smelser Pass occur in the New Pass Range, south of the principal Star Peak outcrop region.

During the middle part of Karnian time, a break in deposition, accompanied by erosion, channeling, and development of solution caves (Nichols, 1972) within the Smelser Pass, took place at least in the northeastern part of the Star Peak outcrop area. This was followed be deposition of coarse conglomerate and other clastic rocks that form the lower part of the Cane Spring Formation. To the west and south these clastic rocks tongue out, but the base of the Cane Spring could nevertheless rest disconformably on the Smelser Pass. Following this brief but widespread tectonic interruption of the carbonate depositional pattern, upper Karnian platform carbonate strata of the Cane Spring Formation blanketed not only the older platform but also extended westward beyong the limits of present-day Star Peak exposures (Fig. 31F). This westward shift of the platform margin in late Karnian time may have extended at least as far as the northwestern Sierra–eastern Klamath belt, where the only significant amount of carbonate rock in the primarily volcanic and clastic Triassic section is the Hosselkus Limestone of late Karnian age. If this shift occurred, the carbonate platform during Cane Spring deposition would have extended at least 100 km beyond the present northwesternmost Star Peak exposures. This distance is based on restoration of the northwestern Sierra-Klamath belt to its possible pre-Tertiary position with respect to northwestern Nevada, following Hamilton (1969, Fig. 4).

Paleotectonic Interpretation

The mid-Karnian interruption in Star Peak deposition was the result of a more widespread tectonic disturbance that affected areas far beyond the Star Peak region. Pronounced uplift and erosion to the north and northeast of the Star Peak region during this time is indicated by the increase, in these directions, in thickness and clast size of the basal conglomerate unit of the Cane Spring Formation. Although the stratigraphy of the Star Peak Group does not further reflect the nature of this tectonic event, it does record an episode of significant regional relative uplift.

Earlier tectonic events during Middle Triassic time were localized within the Star Peak outcrop area and produced stratigraphic patterns from which additional tectonic inferences can be drawn. Relative uplift during the Ladinian in the central part of the region is especially well documented by the Star Peak stratigraphic record. However, the boundaries of the uplifted area are not adequately displayed, so its is uncertain whether the mechanism was faulting or folding. During late Anisian time, prior to local uplift, relatively deep-water, open-marine strata of the Fossil Hill rock unit were laid down across the entire region. Then, following relative uplift, the locally emergent area was eroded while deposition continued to the east, south, and west of it. The basinal upper member of the Prida Formation was deposited to the west and southwest, and the peritidal Home Station Member of the Augusta Mountain Formation was deposited to the east and southeast. In late Ladinian time, the widespread evaporitic dolomite of the Panther Canyon Member accumulated across the uplifted and beveled area.

The earlier Middle Triassic episode of local uplift that took place during early Anisian time, although not so well defined, seems to have had the same general pattern as the subsequent Ladinian uplift and to have been on the same regional scale. Initially, during latest early Triassic time, ammonite-bearing limestone may have been laid down over a wide area, part or parts of which were then uplifted and eroded, only to be blanketed again by open-marine upper Anisian deposits of the Fossil Hill.

This pattern of local relative uplift accompanied elsewhere within the Star Peak region by uninterrupted deposition can be interpreted two ways. The uplifted blocks may have undergone successive episodes of uplift and subsidence, and erosion of them would have taken place when they emerged above sea level, which remained constant. Alternatively, blocks of various sizes may have undergone episodes of differential subsidence during a time of continually lowering sea level so that down-dropping blocks that lagged behind would have had their tops eroded when falling sea level caught up with them. Because uplift and erosion seem to have occurred twice during Middle Triassic time, we prefer the second alternative. The amount of drop in sea level required by this explanation would seem to be too great to be eustatic. Therefore, we suggest that during Middle Triassic time the entire region was broadly upwarped resulting in crustal extension accompanied by the episodic tensional subsidence of local areas of varying size and shape. This paleotectonic interpretation, at least for earlier Star Peak deposition, accords well with that envisaged for the still older Koipato Group which in the southern Tobin Range was found by Burke (1970a, 1973) to have been deposited concurrently with block faulting.

Putting these inferences in larger perspective, the Sonoma orogeny, which resulted in thrust emplacement of the upper Paleozoic oceanic rocks of the Golconda allochthon during latest Permian or Early Triassic time, was followed during the Triassic by regional crustal extension and local differential subsidence during deposition of the dominantly volcanic Koipato Group and carbonate rocks of the Star Peak Group.[1] The abrupt change during mid-Late Triassic time from Star Peak carbonate platform sedimentation to that of the rapidly deposited, terrigenous clastic, pelitic and sandy strata of the overlying Auld Lang Syne Group may relate to another fundamental change in tectonic regime, such as the beginning of the Sierra Nevada magmatic arc.

[1] Speed (1977) has recently suggested that the western and southern limits of lower Mesozoic deposition in northwestern Nevada coincide approximately with those of a vast volcanic arc assemblage which everywhere underlies the lower Mesozoic rocks but rarely crops out. This arc-related assemblage is envisaged as having moved relatively westward toward the continent during the Sonoma orogeny, squeezing out the Golconda allochthon before it. Thermal contraction of this arc is then called upon to produce subsidence of the lower Mesozoic basin. The Star Peak outcrop area constitutes only a small, peripheral part of this basin and may not reflect the principal deep-seated tectonic controls on deposition. Nevertheless, patterns of sedimentation within the Star Peak Group, as described above, require at least local uplift. They cannot be explained by subsidence alone.

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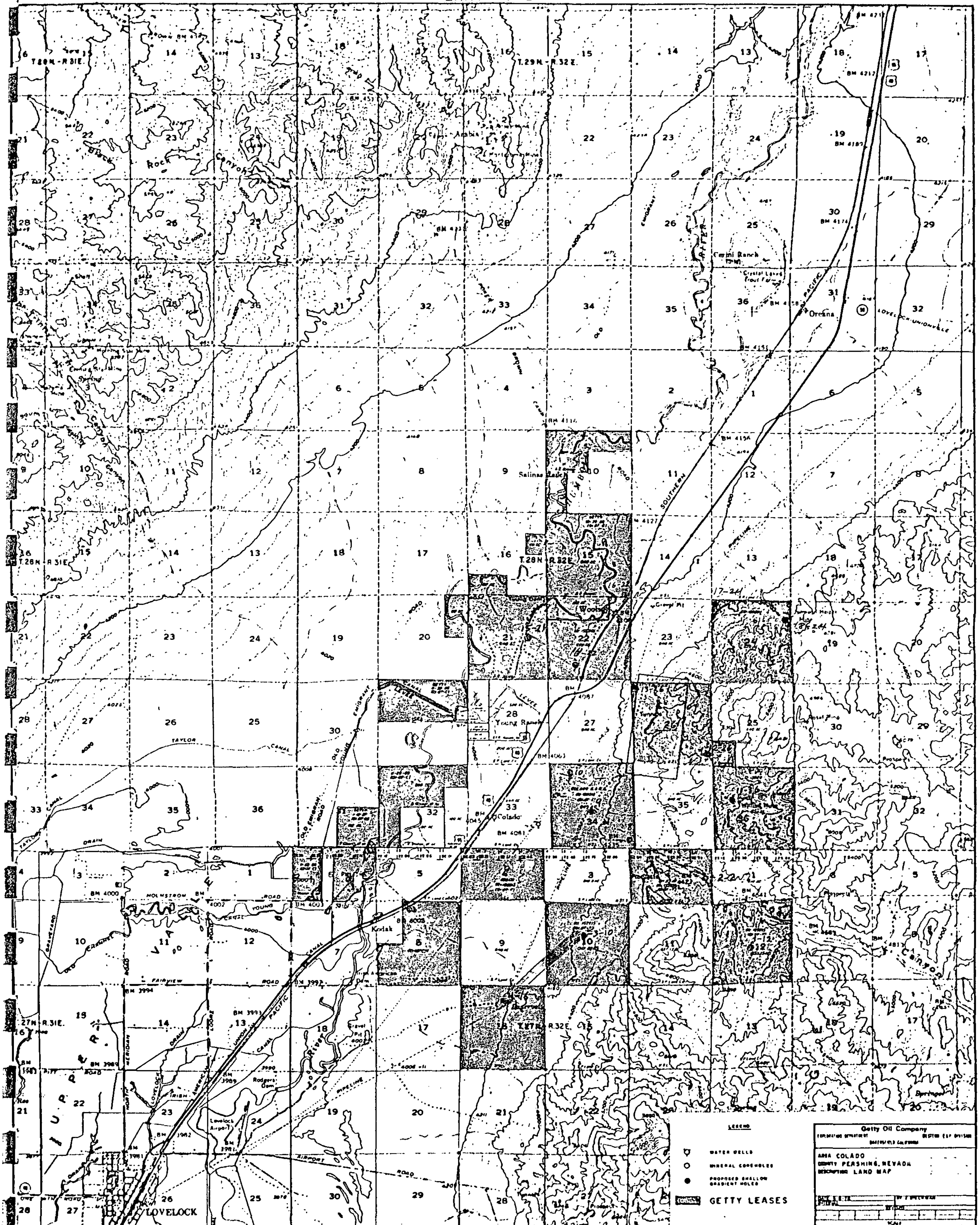
EXHIBIT 1



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Black Rock Canyon
Arabia
Crystal Ranch
Oreana
Lovelock-Unionville
Salinas Ranch
Southern
Pacific
Woolsey
Young Ranch
Colado
Taylor
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Holmstrom
Road
Young
Kodak
Fairview
Road
Upper
Valley
Pipeline
Lovelock Airport
Airport
Lovelock
Springer
LEGEND
WATER WELLS
MINERAL COREHOLES
PROPOSED SHALLOW GRADIENT HOLES
GETTY LEASES
Getty Oil Company
AREA COLADO
COUNTY PERSHING, NEVADA
DESCRIPTION LAND MAP

Tvs - rhyolitic rocks. & assoc. sediments.

Jgd - horn. gabbro

Jl - Lovelock Fm. micrite & gypsum

Jm - Carbonate breccia

(slate) no Fm. name

JꞦs - pelite, Ls, Ss.

no. form. name

Ꞧs - pelite & Ss.